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ACTUATION AND SIMULATION OF A MINISYSTEM WITH FLEXURE HINGES

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Abstract: *In this paper is presented a minisystem with flexure hinges. Compliant mechanisms are jointless mechanisms that rely on elastic deformation to transmit forces and motion. Such systems are particularly amenable to embedded sensing for haptic feedback and embedded actuation with active-material actuators. The miniactuators for minisystems include elements made of so called intelligent or smart materials. In general, the compliant mechanisms are bonded or embedded piezoelectric actuators and/or sensors. The piezoceramic actuator generates a large actuating force and has a fast time response. The response of the minisystem is predicted by the finite elements method. The compliant mechanism and piezoactuator displacements are analyzed and simulated. In the end there is presented a comparison of the experimental results for the same actuator but for different types of signals with theoretical results.*
Keywords: *flexure hinge, compliant mechanism, piezoactuator, minisystem.*

1. INTRODUCTION

Designs in nature are strong but not necessarily stiff; they are compliant and often have embedded actuation and sensing capabilities. Engineered devices, on the other hand, are traditionally designed to be strong and stiff. By assuming individual components to be infinitely rigid, engineers create complex assemblies to perform electromechanical functions and then deal with problems due to wear, backlash, and noise in order to meet precision, cost, and reliability requirements. Furthermore, actuators and sensors are integrated as an afterthought. However, many practical benefits can be realized by exploiting elasticity with a unique opportunity to create monolithic compliant mechanisms with embedded sensing and actuation [1, 2, 3]. A compliant system is comprised of jointless, monolithic, flexible mechanisms with integrated actuation. The miniactuators for minisystems include elements made of so called intelligent or smart materials.
The term compliant mechanism refers to a larger field that includes living hinges and flexures. Compliant mechanisms are jointless mechanisms that rely on elastic deformation to transmit forces and motion. The lack of traditional joints in these single piece flexible structures offers many benefits, including the absence of wear debris, pinch points, crevices, and lubrication. They can be designed for any desired input-output force displacement characteristics, including specified volume/weight, stiffness, and natural frequency constraints [4]. As flexure is permitted in these mechanisms, they can be readily integrated with unconventional actuation schemes, including thermal, electrostatic, piezoelectric, and shape memory alloy actuators.
Piezoelectricity is defined as a relation between an applied electric field and strain or an applied strain and electric field in certain crystals, ceramics, and films (Fig. 1) [5].

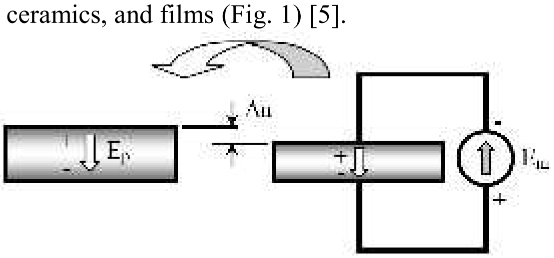


Figure 1: Piezoelectric actuation through the reversed piezoelectric effect

In general, compliant mechanisms with flexure hinges are bonded or embedded in piezoelectric actuators and or sensors. The piezoceramic actuator generates a large actuating force and has a fast response time. Moreover it is smaller than other actuating systems as electrical motor or hydraulics for the same force.

2. DESIGN OF MINISYSTEM

In this paper, we propose a minisystem with a compliant mechanism and flexure hinges with minimizing the overall dimensions. We realized three constructive variants of compliant minigrippers with flexure hinges from a single piece (monolithic structure). The task for design is to find the variant, with same shapes but different dimensions in order to satisfy desired characteristics under specified constraints. These are: range of motion for fingers, maximal external dimensions, displacement and characteristics of material.
Following is presented the first variant realized of the compliant minigripper (Fig 2).

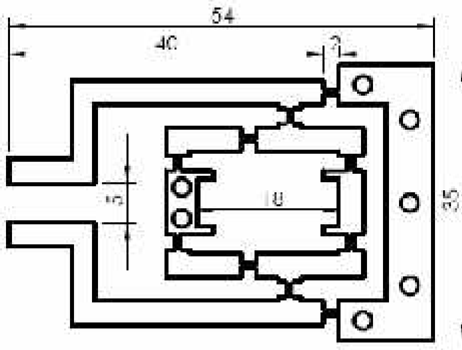


Figure 2: Overall dimensions for first compliant minigripper

The compliant minigripper is built to enhance the input motion provided by the piezoelectric actuator. The operation depends on the design of its mechanism which transmits the motion and force to the gripping fingers. The compliant minigripper is realized from alloy steel and is actuated by a stack piezoelectric actuator.
The analytical equations for piezoelectric actuator displacements are [6]:

$$u_{Gx} = (qU - F)/c_T \tag{1}$$

Where U is voltage; q – force factors; F – axial force; c_T – rigidity
The clamping force F_0 is:

$$F_0 = qU_{\max} \tag{2}$$

The time for response is:

$$t_r = \frac{1}{2f_r} \tag{3}$$

where f_r is the resonant frequency.
Miniaturization alone is insufficient, for the many devices to work together, microelectronics need to be incorporated in the system. The reduced dimensions imply different manufacturing technologies, measuring and control techniques and specific actuation methods based on new types of actuators. Their actuation effect is achievable through three different means: field interaction, mechanical interaction and induced limited strain. The actuators in the last category include elements made of so called intelligent or smart materials: piezoelectric and magnetostrictive materials, electro/magnetorheological fluids, electroactive polymers, shape memory alloys.
Performance constraints may include minimizing the energy loss in the mechanism, obtaining desired motion amplification (geometrical advantage) or force amplification (mechanical advantage) [7].
For minisystem the geometrical advantage (GA) is defined as the ratio of output displacement (u_{out}) to input displacement (u_{in}) given the relation:

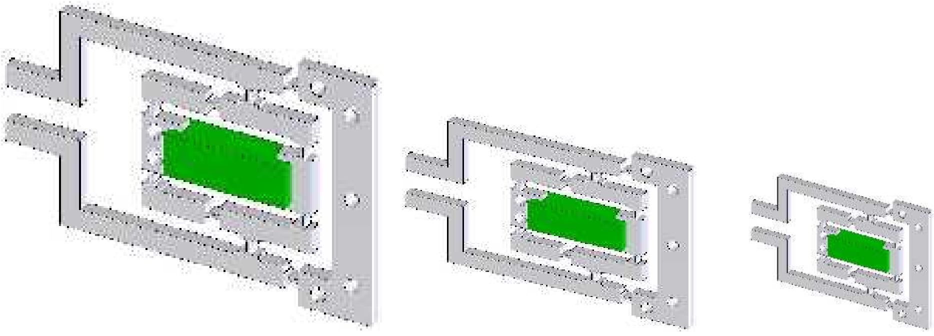
$$GA = \frac{u_{out}}{u_{in}} \tag{4}$$

The mechanical advantage (MA) is defined as the ratio of output force (F_{out}) to input force (F_{in}) given the relation:

$$MA = \frac{F_{out}}{F_{in}} \qquad \textbf{(5)}$$

Once a feasible topology is established, performance constraints can be imposed during the following stage in which size and shape optimization are performed. The principle of compliant design scales well, making these mechanisms suited for applications at micro- and macroscales.

In this paper we realized three constructive variants for minisystem: the first has a piezoactuator with displacement 1-15µm, and overall dimensions 18x6.5x6.5 mm (fig. 3a); the second has a piezoactuator with displacement 1-9.1µm, and overall dimensions 10x3.5x4.5 mm (fig. 3b) and the last has a piezoactuator with displacement 1-4.6µm, and overall dimensions 5x3.5x4.5 mm (fig. 3c).



a b c

Figure 3: Solid model for all three variants from the minisystem

All the ten flexure hinges of the compliant mechanism are identical and have corner-filleted configuration.

The size of a system and the physical parameters will be modified with a scale factor S. When the scale size changes, all the dimensions of the object change by exactly the same amount S such that 1: S. This scale factor S can be used to describe how physical phenomena change. Knowing how a physical phenomenon scales, whether it scales as S^1 or S^2 or S^3, or S^4 or some other power of S, guides our understanding of how to design small mechanical systems [8].

3. ANALYSIS OF THE MINISYSTEM

The geometric parameters shown in Fig. 2 have been used to run the finite element simulation. For the first minisystem it was considered the thickness of the compliant minigripper 2.21 mm [9].

Driving a piezoelectric actuator requires sourcing sufficient current from the driver to produce the desired electrical field or voltage level in the PZT stack. The study was performed for the following inputs: voltage is 0 ÷150 [V] and ramp signal. The Geometric Advantage resulted on the compliant minigripper after FEM analyses are presented in the figure 4.

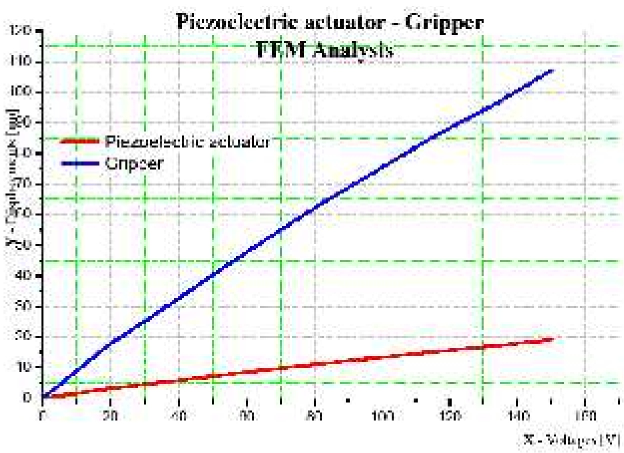


Figure 4: Results for the FEM analyses

The material used for analysis of the compliant minigripper is alloy steel with: $E = 2.1x10^5$ N/mm^2 and Poisson's Coefficient = 0.31.

For the first configuration resulted after analysis:

$$GA = \frac{u_{out\_first}}{u_{in\_first}} = 6.5$$

Based on material constraints permissible stress, strain, fabrication constraints minimum feature size, etc, external loads, and desired mechanical advantage, the exact size, shape, and geometry of each of the compliant mechanism elements are optimized [10]. The objective function is problem specific, depending on the application of the compliant mechanism.

4. EXPERIMENTAL RESULTS

In the next figure is presented the first constructive variant of a compliant minigripper in the structure of the studied minisystem (Fig. 5):

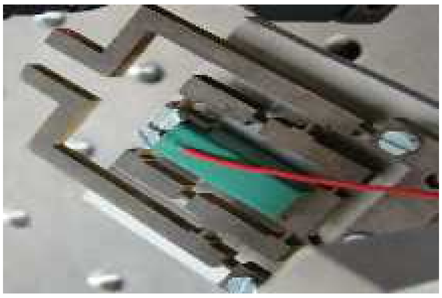


Figure 5: The experimental structure

Actuation technologies are quite problematic at small scales. For command and control of the minisystems with data acquisition board DSpace, is made a Simulink model that generates the command signals using the Signal generator blocks. The signals type can be: step, sinusoidal, ramp, impulse, etc. Real-time view behavior of the system will be through the Control Desk application.
The study was performed for the following applied input voltage: 0; 20; 40; 60; 80; 100; 120; 150 [V] and the material used for analyze of the compliant minigripper is alloy steel with: E = 2.1×10^5 N/mm^2, Poisson's Coefficient = 0.31.
In the next figures are presented the ramp signal, sinusoidal signal and step signal results:

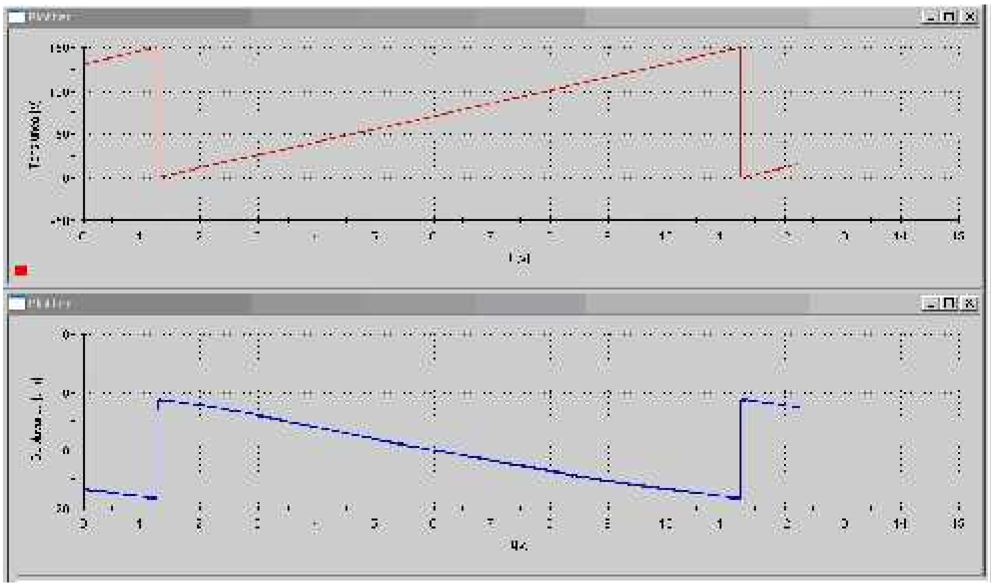


Figure 6: Results for ramp signal

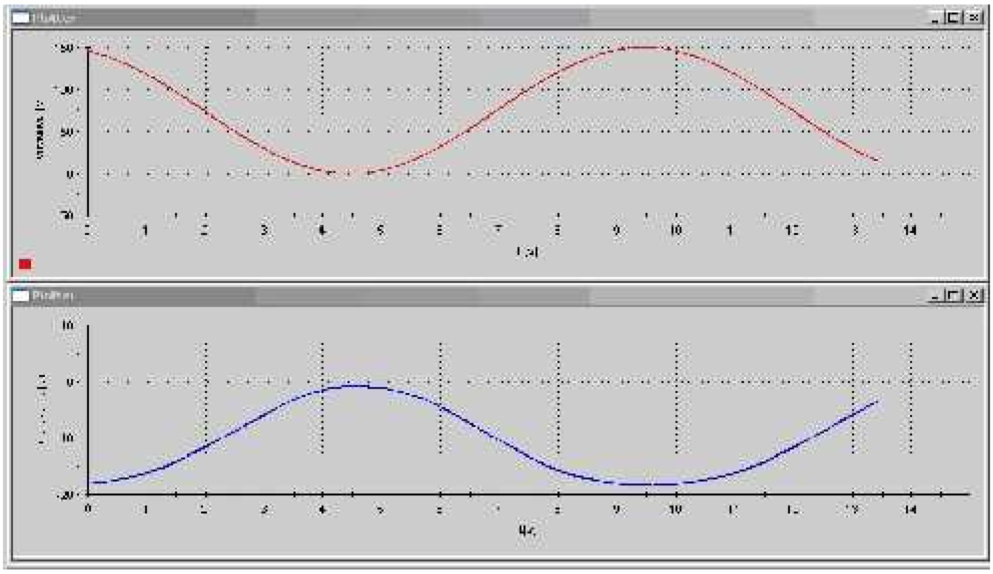


Figure 7: Results for sinusoidal signal

A piezoelectric actuator acts like a spring, the force developed is not constant over its range of motion. The force available from a piezoelectric actuator progressively decreases as it extends. To compensate position change, one must drive the piezoelectric actuator to a slightly different voltage in the return movement to get back to the same starting position. The value of the stroke hysteresis is a percentage of the entire commanded stroke.

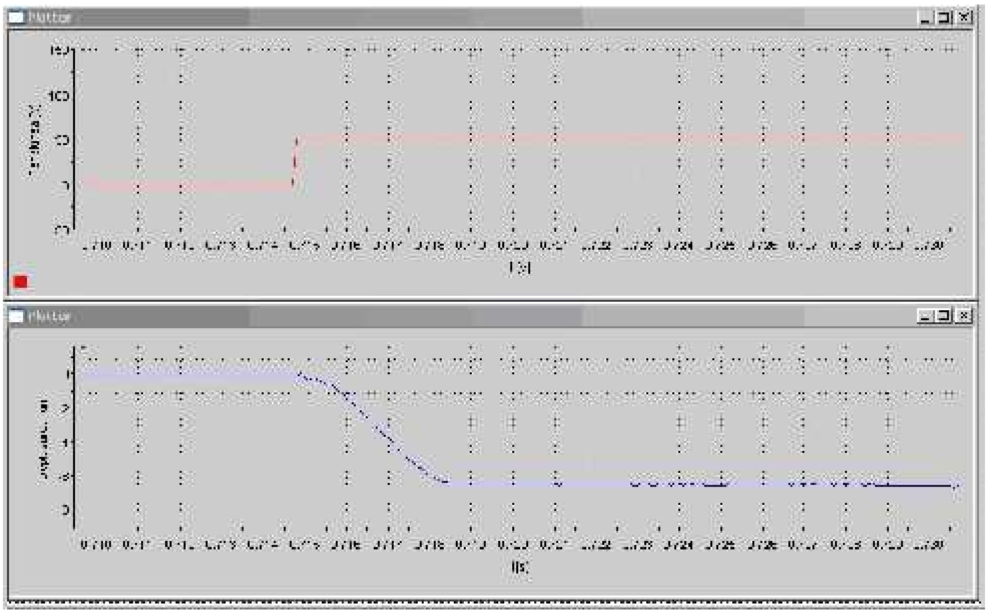


Figure 8: Results for step signal

As it can be observed from the above figures the resulted obtained in the ramp signal case are better than the other ones.

5. CONCLUSIONS

We proposed a new minisystem with flexure hinges and piezoelectric actuation with study time response for different input signal.

Unconventional actuators such as shape-memory alloys, piezoelectric or magnetostrictive actuators, or electrically active polymers are very important for minisystems. Because the PZT stack is a displacement generating device and only develops force as its expansion is resisted, the amount of displacement and remaining pushing force are dependent on the stiffness of the applied load.

The control is achieved in closed loop, with a reaction by position; it is necessary to measure the actuators displacements using suitable position sensors; the control of supply voltage of actuators is such that it can be done the exact position required by the mechanism action.
The compliant minigrippers can be successfully applied to the fields that need high precision in small workspace, such as: optics, precision machine tools and mini component fabrication.

ACKNOWLEDGMENTS

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