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Research Concerning the End-effectors for SiMFlex Microgripper

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Abstract. In this paper the SiMFlex microgripper are designed and modelled. The result for FEM analysis for SiMFlex was presented. The prototype for SiMFlex microgripper is realized with non-conventional technologies and the design included flexure hinges and piezoelectric actuators. A study for different surface qualities for end-effectors is presented and used two materials for active parts of jaws manufactured. Simulations and experimental part were generally performed on the system and special attention was given to jaws that were illustrated and clarified by these studies. Based on the results obtained the optimization solutions for end-effectors for SiMFlex microgripper will be realize.

1. Introduction

The compliant mechanisms are a distinct field in research, and they use elastic deformation for the transmission of the forces and movements. The compliant mechanisms are built by flexure hinges and connecting elements, so the characteristics of manufacturing material are a very important influence for transmission the displacements in the structure. All the displacements are done from flexure hinge and the deformation will respect de Hook law [1]. Also, the flexure hinge can be designed in different shapes in this way, various displacements for same overall dimensions will be done [2]. There are many advantages of using the compliant mechanisms: they can be built in monobloc structures, they have reduced dimensions, they don't need lubrication, they reduce the noise and frictions, etc.

The trend during the last years is the miniaturization of the product and of the tools necessary in industrial process, including the micro-assembly. For micro-assembly the best device are microgrippers built such as the compliant mechanisms [3]. Research in microgrippers had already started, mainly lead in Europe, SUA and Japan teams and usually, at microgrippers it used the micro-actuation with specially proprieties so-called smart materials (shape memory alloys, piezoelectric, magnetoelectric, ferrofluidic, etc) [4], [5]. The manipulation of micro-objects, are perturbed by so-called surface forces such as capillary forces, due to scaling laws, when they are to assemble the small components. These forces are usually neglected in usual macroscale assembly, which is ruled by gravity [6 - 12].

In this paper, a new design for a micromanipulation system is proposed with compliant microgripper and piezoelectric actuator. The compliant microgripper has attached the changeable jaws. The active parts of the jaws were manufactured from different materials, in order to use them for a large field of applications.

2. Analysis of SiMFlex

In this part a system for micromanipulation with monolithic and symmetric compliant mechanical structure is designed and analysed. The proposed whole system is shown in figure 1, where, there are three main parts: piezoelectric actuator, compliant microgripper and microgripper's jaws.

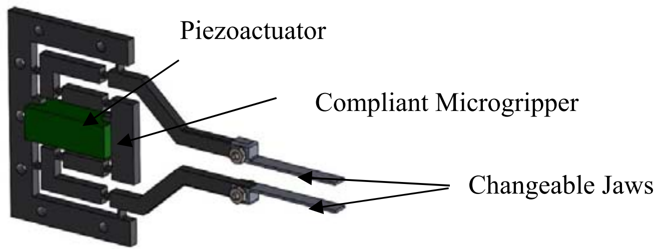

Figure 1. 3D Model for SiMFlex Microgripper.

The piezoelectric actuator has an axial deformation which represents the input for the compliant microgripper. The compliant microgripper was built with ten flexure hinges in order to eliminate the assembly errors. In the end, the changeable jaws are attached to the microgripper end-effectors, for being used for a large variety of micro-objects with different surfaces and materials for micromanipulation.

2.1. Piezoelectric actuator analysis

At first, the piezoelectric actuator was analysed with its axial deformation capability and then everything is incorporated into the model of the compliant frame. The analysis of the stack piezoelectric actuator with following specifications was realized: maximum voltage 150 V; maximum stroke 18 µm; capacitance 1350 nF; blocking force: 1000 N; resonant frequency: 65 KHz; Young's modulus: 4.4×10^{10} N/m^2 and overall dimensions are 6.5mm x 6.5mm x18 mm [13].

The analytical equations for displacements piezoelectric actuator are:

$$\Delta L = \mathrm{E} \cdot \mathrm{d_{ij}} \cdot L_0 + \frac{F}{c_T} \tag{1}$$

where: E is electric field; d_{ij} - piezoelectric coupling coefficient; L_0 – actuator length; F – axial force; c_T - rigidity

$$\Delta L = \Delta L_0 + \frac{F}{c_T} \tag{2}$$

$$\Delta L = (q \cdot U_a - F)/c_T \tag{3}$$

where: q is the factor for force and U_a is voltage actuator.

$$\Delta L_0 = \frac{F_0}{c_T} \tag{4}$$

$$F_0 = qU_{\max} \tag{5}$$

The displacement for piezoelectric actuator was calculated for the input voltage U (0 ÷150) in a ramp signal, which resulted as input displacement for microgripper.

2.2. Displacement Amplification

Monolithic structure as compliant microgripper SiMFlex is manufactured with ten flexure hinges by Polyetheretherketone (PEEK) and overall dimensions 54mm x 41mm x 3mm. The jaws are fixed on compliant microgripper and have overall dimensions 20mm x 3mm x1mm.

Finite element simulation has been performed using the whole mechanical structure that is obtained from the microgripper and jaws, as it shown in figure 2. There are holes fixed and one guided member where the object will be positioned. In this case of the simulations considered, the output point is free, a condition for which the displacement amplification has been evaluated by means of the resulting input and output displacements.

The result for numerical analysis for maximum input displacements can be shown in figure 2 and the displacement histories of the output versus the input displacement is shown in figure 3.

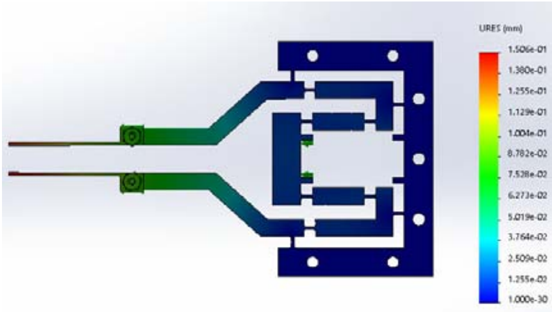

Figure 2. The maximum displacement of SiMFlex microgripper.

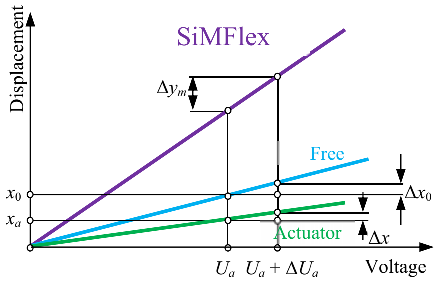

Figure 3. SiMFlex microgripper and piezoelectric actuator characteristics Displacements -Voltage.

One functioning characteristic of the compliant microgripper is the so-called geometrical advantage (GA), which is the output displacement to input displacement amplification ratio. Taking any two measurement points defined by voltages U_a and $U_a + \Delta U_a$, that are applied to the actuator, displacement Δx_a is obtained. The displacement Δx_a is input for the compliant microgripper. The output displacement Δy_m results from the two linear characteristics that define the output and input displacements of the system.

The geometrical advantage [14] is therefore calculated as:

$$GA = \frac{\Delta y_m}{\Delta x_a} \tag{6}$$

When the geometrical advantage was calculated only for the compliant microgripper without jaws, its value was: $GA = 3.47$.

2.3. Surface quality for jaws

When a manipulation of micro objects is performed, there is often a disturbance given by the adhesion between the micro-object and the jaws of the microgripper. Electrostatic forces are among the phenomena responsible for this adhesive effect.

For the increasement of the variety of the manipulated micro-objects the SiMFlex active parts of the jaws are changeable. The active parts of the jaws are manufactured out of two different materials: cooper and aluminium.

For a better control of picking and releasing micro-objects, in the next chapter, the surface roughness for each active part of jaws prototype will studied.

3. Experimental Results

The structure of the test bench for measurements contains a Laser displacement sensor with resolution of 0,01 μm and the response time of 100 μs. For collecting data of piezoelectric actuator and compliant microgripper, the command in Simulink and the application ControlDesk were realized.

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3.1. Characterization for the actuator and compliant microgripper

The experimental tests were started with the stack piezoelectric actuator which was powered by the input voltage U = 0 ÷ 150V on the ramp signal which was recorded together with the output actuator's displacement. The measured results for piezoelectric actuator can be seen in figure 4, and the comparison between calculated and measured displacements is presented in figure 5.

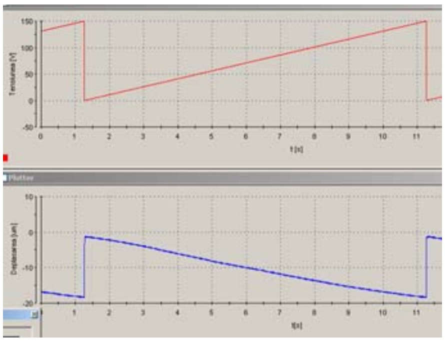

Figure 4. The experimental results of the ramp signal for stack piezoactuator.

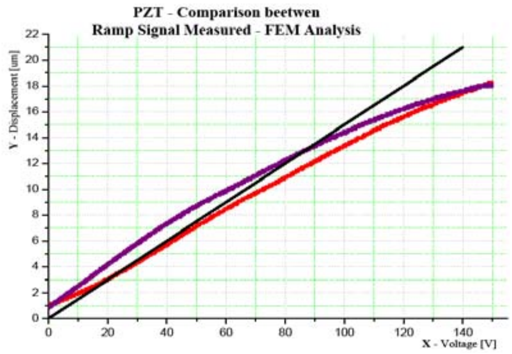

Figure 5. FEM analysis versus experimental results displacements piezoactuator.

In the second part, the out displacements for SiMFlex microgripper was measured. For this study, the same testbench with laser sensor and control desk application were used. The results obtained after the measurements were performed for SiMFlex microgripper without jaws.

This can be seen in figure 6.

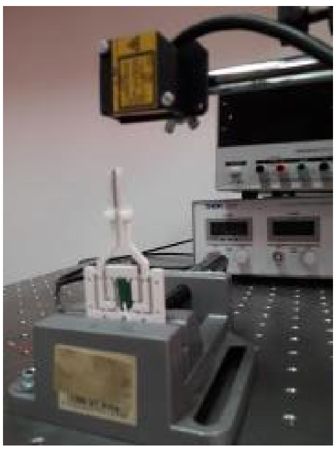

Figure 6. The gripper prototypes.

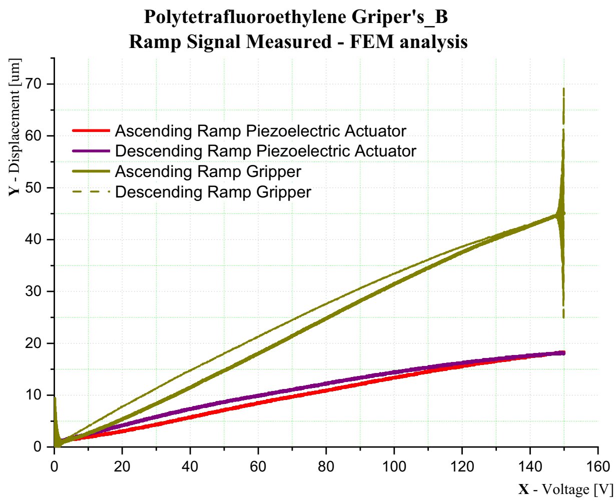

Figure 7. The experimental results of the ramp signal for stack piezoactuator versus SiMFlex microgripper without jaws.

The experimental results show the input and output displacements (figure 7) as such, the geometrical advantage can be estimated. Its value was: $GA = 3{,}11$.

The finite element simulations are performed to verify the accuracy of the model. The results are in a good agreement with those produced by the experimental approach.

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3.2. Characterisation of the surface quality for jaws

An objective for SiMFlex microgripper is to use in more fields of activities, and the active parts of jaws were manufactured from two materials with different characteristics: bras and aluminium.

The AFM analysis was performed using a Veeco Dimension 3100 atomic force microscope, operated in contact mode. The vertical resolution of the microscope is < 1 nm. The cantilevers used for imaging were silicon nitride, Bruker SNL-10, having a nominal tip radius of 2 nm.

In figures 8 and 9 it can show the quality for each surface.

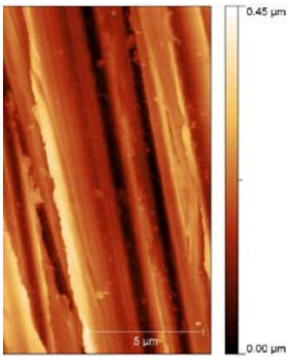

Figure 8. The surface analysis of bras jaws SiMFlex microgripper.

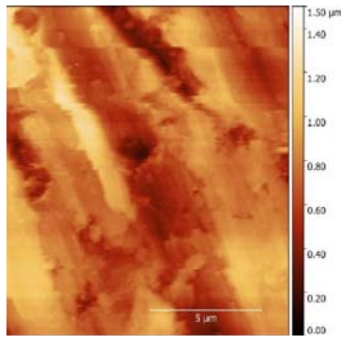

Figure 9. The surface analysis of aluminium jaws SiMFlex microgripper.

In the end, the quality of jaws surfaces is analysed. The result for brass, had a rugosity: RMS: 69.2 nm for peak-to-valley distance: 400.5 nm. On the other hand, for aluminium jaws, the surface had a rugosity RMS: 194 nm for Peak-to-valley distance: 1.406 µm.

In the future, the application for each active part of jaws will be studied.

4. Conclusion

This paper presents a compliant microgripper which has a monobloc geometry that minimizes construction complexity and increases robustness, while preserving the advantages of flexure joints.

This is a study based on small-displacement response of SiMFlex compliant microgripper with ten flexure hinges. The microgripper's geometrical advantage was emphasized. The finite element analysis predictions are confirmed by experimental testing of the SiMFlex microgripper prototype.

The structure and function of the experimental test bench for a compliant minigripper are presented. The measurements validate the FEM analysis for the Polyetheretherketone material. In the end, the surfaces used for jaws manufactured, made of two different materials, were studied. The jaws will be used for many types for microbject manipulation.

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