A SENSORIZED µELECTRO DISCHARGE MACHINED SUPERELASTIC ALLOY MICROGRIPPER FOR MICROMANIPULATION

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Abstract

This paper describes a novel microgripper, fabricated in superelastic alloy (Ni50.8Ti49.2) by wired micro Electro Discharge Machining (µEDM). The main features of the new microgripper are fabrication technology (µEDM) and exploited material (superelastic alloy); the gripper was sensorized with commercial semiconductor strain-gauges and implemented in the force-feedback micromanipulation workstation developed in the authors’ laboratory. Both FEM simulation and results of experimental characterizations are presented.

Introduction

This microgripper was designed by exploiting the know-how acquired through previous activities on micromanipulation and microtools in the authors’ laboratory, when LIGA and laser machined grippers in nickel and steel were used [1]. The microgrippers fabricated in nickel by exploiting the LIGA technique were based on mechanical flexure joints; slightly different designs were used to obtain different mechanical performances. Essentially two different sets of microgrippers were fabricated: the average size of the microgrippers are 7 x 15 x 0.4 mm³ for the first set; and 10 x 25 x 0.2 mm³ for the second set. LIGA fabricated grippers were all actuated by PZT (high and low voltage) and were sensorized by commercial semiconductor strain-gauges in order to provide a force feedback signal to the operator [2]. After proper calibration the maximum forces generated by the gripper were 22 and 7 mN for the first and the second set, respectively [3,4]. As shown in Table 1 below, we compared the main features of the grippers with those of a commercial one (Bartels Mikrotechnik GmbH), devoted to similar applications.
The work/mass parameter confirmed that the gripper design with flexure hinges allows obtaining good energy efficiency.

Table 1 about here

In order to have a tougher device suitable for micromanipulation tasks in different environments a similar design but different material and fabrication technology were exploited for the next gripper generation. For the intended micromanipulation applications (handling and assembly of tiny mechanical components for fabricating miniature machines, manipulation of biological microsamples during tissue characterization tasks), a small volume microgripper with maximum span of ~1 mm, robust behavior and accurately controllable (e.g. piezoelectrically actuated) is needed.

**Microgripper Design and Fabrication**

In Figure 1 both a picture of the newly designed microgripper and an enlarged view of a mechanical detail (flexure hinge) are showed. Overall dimensions of the microgripper are $15.5 \text{ mm} \times 8.4 \text{ mm} \times 0.5 \text{ mm}$, with an opening span of $800 \mu\text{m}$. The thinnest beam has a width of $100 \mu\text{m}$ and a length of $700 \mu\text{m}$, and the smallest radius of curvature is $\sim 55 \mu\text{m}$.

Figure 1 about here

For preliminary tests with the novel design we elected laser machining as fabrication technique, and spring stainless steel (chrome-molybdenum steel) as material. In the design phase an ANSYS linear analysis, aimed at calculating theoretical fingertip displacements (Figure 2) and Von Mises stresses (Figure 3) for the microgripper structure was carried out.

Figure 2 about here
As showed in Figure 2, the simulations performed for the stainless steel microgripper (Young's Modulus $= 210000$ MPa), by imposing an actuation force of 7 N and an actuation displacement of 100 $\mu$m, resulted in a displacement of each tip of $\sim 180$ $\mu$m (with an amplification factor of 2). On the other hand, by imposing a tip displacement of 400 $\mu$m (which would have completely closed the gripper), the stress in the stainless steel flexure joints exceeded the yield strength ($\sigma_{\text{max}} \sim 1500$ MPa $>$ $\sigma_{\text{adm}} \sim 515$ MPa - Figure 3). Moreover, the force to be generated by the actuator in order to produce the tip displacement necessary for full closure had to be increased up to 18 N.

In order to improve gripper performances in terms of mechanical amplification factor, actuation forces and structure reliability, simulations with different materials have been carried out. Superelastic alloy is often the material of choice for microstructures based on flexure joints because of its favourable mechanical properties [5-7]. Because of a limited displacement in the elastic range, each design of flexure joint microstructure is a trade off between the need for large displacement and the requirement of minimum stress in material. The simulations performed for a superelastic alloy structure are showed below (Figure 4 and 5). The material is Ni50.8Ti49.2.

By imposing the same actuation force and the same actuation displacement, for the superelastic microgripper (Young's Modulus $= 210000$ MPa) the displacement of each tip was of $\sim 400$ $\mu$m (amplification factor of 4), enough for obtaining a full closure of the gripper fingertips (Figure 4).
Moreover, by imposing a tip displacement of 400 \( \mu \text{m} \), the microgripper flexure joints work in a safe elastic range, with \( \sigma_{\text{max}}=584 \text{ MPa} < \sigma_{\text{adm}} \approx 600 \text{ Mpa} \) (Figure 5). These results confirm that superelastic alloy matches our requirements of span and robustness better than more standard materials, e.g. stainless steel.

The selected fabrication technique was micro-Electro Discharge Machining (\( \mu \text{EDM} \)), which allows to fabricate high aspect-ratio structures made out of different conducting and semiconducting materials with good surface finishing and without relevant thermal alterations even in the smallest features. When machining superelastic alloys, this last characteristic is of great importance in order not to alter material properties. Moreover, \( \mu \text{EDM} \) is an elective choice to machine hard materials.

**Displacement and Force Characterization**

Two microgrippers, in spring stainless steel and superelastic alloy were fabricated, by laser machining and \( \mu \text{EDM} \), respectively. Both prototypes were assembled in a suitably shaped brass housing (Figure 6) and characterization tests were performed. A commercial low voltage multilayer piezoelectric stack (APA100S, CEDRAT RECHERCHE SA) with a maximum stroke of 100 \( \mu \text{m} \) at 150V was used as actuator.

The following step was the mechanical characterization in position by means of a laser gauge (Mel, M25L/0.5-10B24NK) and in force by means of a load cell (GM2 3M, PTC Electronics Inc., full scale 300 mN, accuracy 0.01 mN) of both grippers.

The graphs (Figure 7 and 8) show the comparison between the experimental measurements obtained with the two different microgrippers. Preliminary results are consistent with simulations: as stated above, the microgrippers fabricated in superelastic alloy (red markers) have better performances in terms of maximum fingertip displacement (Figure 7) and exertable force (Figure 8).

With a driving voltage of 150 V, a tip displacement of about 395 \( \mu \text{m} \) per finger was measured: by considering the possible displacement loss due to the assembly tolerances,
this result is in good accordance with the theoretical model (400 \(\mu\)m). From a linear fit we find the average amplification factors (a.f.) over the whole displacement interval: for the superelastic gripper a.f. = 3.9 \(\pm\) 0.1 and for stainless steel gripper a.f. = 2.1 \(\pm\) 0.1.

In Table 2 stainless steel and superelastic alloy microgrippers parameters are illustrated.

<table>
<thead>
<tr>
<th>EDM Gripper</th>
<th>Tip Displ. (microns)</th>
<th>Max Force (mN)</th>
<th>Work (mJoule)</th>
<th>Mass (mg)</th>
<th>Work/Mass (Joule/Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>147</td>
<td>5.9*10^{-2}</td>
<td>158,40</td>
<td>4*10^{-7}</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2:** Superelastic alloy microgripper parameters

Superelastic alloy microgripper has been also instrumented with semiconductor strain-gauges (ESU-025-1000 Entran Devices Inc.). A Wheatstone bridge configuration with two active strain-gauges and two external resistors has been chosen. The sensorized microgripper, mounted on a 3 d.o.f. commercial manipulator (DC3-R-L, Marzhauser-Wetzlar) and teleoperated manually using a haptic interface (Phantom 1.0, SensAble Technologies Inc.), was successfully used both to safely grasp and accurately position micromechanical components, and to test force feedback capabilities manipulating biological samples [8, 9].
Conclusions
A newly designed µEDM superelastic microgripper was presented. Comparisons with previous fabricated microgrippers and with grippers with similar design but fabricated in different material show improvements of maximum exertable force and of work/mass ratio, according to design issues. The microgripper, sensorized in force by means of semiconductor strain gauges, is the core component of the teleoperated micromanipulation workstation developed in the authors’ lab.

Acknowledgements
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References


Table 1: Microgrippers' main parameters comparison.

<table>
<thead>
<tr>
<th></th>
<th>LIGA Gripper (small)</th>
<th>LIGA Gripper (big)</th>
<th>Bartels Gripper</th>
</tr>
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<tr>
<td>Tip Displ. (microns)</td>
<td>500</td>
<td>600</td>
<td>680</td>
</tr>
<tr>
<td>Max Force (mN)</td>
<td>22</td>
<td>6</td>
<td>7</td>
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<tr>
<td>Work (mJoule)</td>
<td>0.0055</td>
<td>0.0018</td>
<td>0.0024</td>
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<tr>
<td>Mass (mg)</td>
<td>77.4</td>
<td>91.00</td>
<td>798</td>
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<tr>
<td>Work/Mass (Joule/g)</td>
<td>7.11E-05</td>
<td>1.98E-05</td>
<td>2.98E-06</td>
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</table>

Fig. 1: a) Superelastic gripper; b) Detail of flexure hinges.

Fig. 2: ANSYS linear analysis: displacements in the stainless steel gripper.
Fig. 3: ANSYS linear analysis: Von Mises stress in the stainless steel gripper.

Fig. 4: ANSYS linear analysis: displacements in the superelastic gripper.

Fig. 5: ANSYS linear analysis: Von Mises stress in the superelastic gripper.
**Fig. 6:** Sensorized EDM superelastic microgripper in a brass housing grasping a polymeric microtube.

**Fig. 7:** Fingertip displacement vs. actuator displacement: comparison between stainless steel and superelastic microgrippers.

**Fig. 8:** Fingertip force vs. actuator displacement: comparison between stainless steel and superelastic microgrippers.
Table 2: Superelastic and stainless steel microgrippers' main parameters comparison.

<table>
<thead>
<tr>
<th></th>
<th>EDM Superelastic Gripper</th>
<th>Laser Machined Stainless Steel Gripper</th>
</tr>
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<tbody>
<tr>
<td>Tip Displ. (microns)</td>
<td>800</td>
<td>240</td>
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<tr>
<td>Max Force (mN)</td>
<td>147</td>
<td>125</td>
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<tr>
<td>Work (mJoule)</td>
<td>0.0588</td>
<td>0.0150</td>
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<tr>
<td>Area (mm²)</td>
<td>43.90</td>
<td>43.90</td>
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<td>Volume (mm³)</td>
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<td>Mass (mg)</td>
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<td>Work/Area (mJ/mm²)</td>
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<td>Work/Volume (mJ/mm³)</td>
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<td>Work/Mass (Joule/g)</td>
<td>3.71E-04</td>
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