TRING-module : a high-range and high-precision 2DoF microsystem dedicated to a modular micromanipulation station

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***Abstract*— As part of a microfactory concept, a micromanipulation station is made up of two independant microsystems having each one two degrees of freedom (rotation and linear motions). That allows the station to manipulate microparts with a high range of dimensions, from $10\mu m$ to some millimeters ($2mm$). This paper presents one of these microsystems called TRING-module.**

I. Introduction

In microassembly and microproducts fabrication, the use of small production systems, called microfactories, present many advantages relatively to the use of conventional production systems [1]: technical aspects (accuracy, etc.), economic aspects (low costs of investment and production, etc.), human problems (portability and easyness for learning, etc.) and environmental aspects (energy saving, etc.). For microfactories, the robots and strategies used are studied differently regarding those of classical factories. The actuator articulations are realised by deformable materials while new micromanipulation strategies are employed to master the adhesion effects. In general, a microfactory is composed of one or several micromanipulation stations inside of which one or more microsystems and microrobots work to accomplish a task.

In the microfactory concept at our laboratory [2][3], a micromanipulation station is made up of two independant microsystems, called TRING-module, having each one two degrees of freedom (rotation and linear motions) (Fig. 1). That allows the station to manipulate microparts with a high range of dimensions, from $10\mu m$ to some millimeters ($2mm$). This paper presents the principle and the experimental results of the TRING-module.

II. Presentation of the TRING-module

When designing the TRING-module, the specifications were the followings [4]:

- the microsystem must have two degrees of freedom (DoF) : linear and angular motions,
- the desired precision must be better than $1\mu m$,
- in each motion, a very high stroke must be possible : more than $5cm$ in the linear motion and $360°$ in the angular one,
- finally, as the microsystem is dedicated to a microfactory, it must have an adequate size. For example, if the range of the linear motion is about $5cm$, the total dimensions of the microsystem and its support should be inferior to $10cm * 10cm * 10cm$.

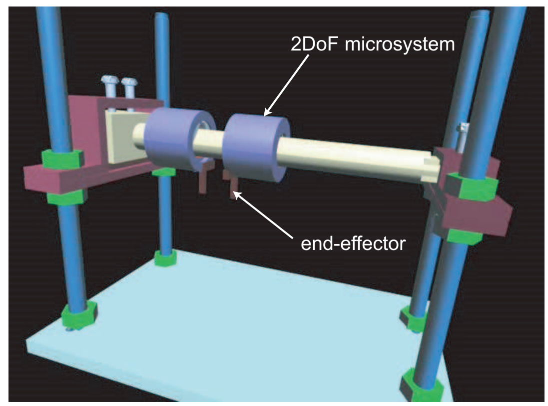

Fig. 1. A micromanipulation station is composed of two independant 2dof microsystems called TRING-module.

To fulfill these requirements, we have proposed the use of a stick-slip microactuator presented in [5]. The main advantage of this actuator is the possibility to have more degrees of freedom within one small bulk material [6].

Besides the dimensions, weight is the main criteria of the design because the torque that the microactuators can deliver to move the microsystem is very limited. The body of the microsystem is then made of aluminium because of the rigidity and the lightness that it offers. So, the load of the whole microsystem is about $100mN$. As the dimensions are small and the shape is complex, the body was fabricated with electro-erosion technology. Fig. 2 shows the microsystem positioned on the glass tube [4].

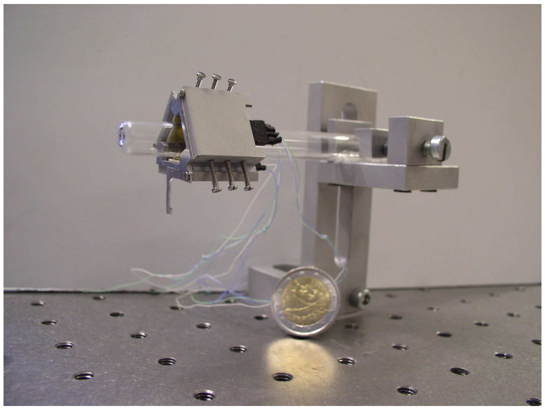

Fig. 2. Photo of the microsystem on the glass tube.

III. Experiments

In this section, we present the results of experiments for each motion : linear and angular. Two characteristics have been identified: small displacement characteristic and long distance characteristic. The small displacement characteristic concerns the step (resolution) that the TRING-module is able to perform. It has been carried out with an optical sensor with $10nm$ of resolution. For the angular measurement, we use the principle shown in the see Fig. 3 such as $tg(\theta) = \theta = \frac{m}{R}$ were θ represents the angular displacement of the microsystem, m is the tangential displacement and R is the radius. Another optical sensor and a capacitive sensor with high ranges were used to characterize respectively the linear and the angular motion in large distance.

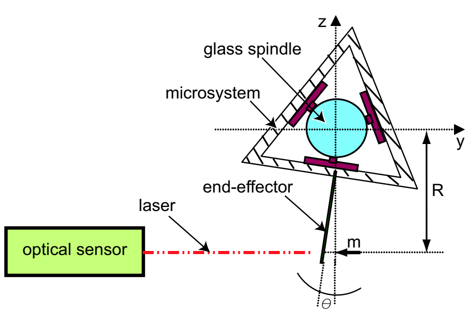

Fig. 3. Principle of measurement of the angular motion in small displacements.

A. Step measurements

The Fig. 4 shows the displacement of the microsystem in linear motion when applying a sawtooth voltage with $\pm 150V$ of amplitude. We conclude that the step is sub-micrometric and is nearly constant during the displacement. However, according to the applied frequency, it changes a little. At $100Hz$, the amplitude of a step is around $100nm$. We observe that the amplitude of the step is $170nm$ for a frequency of $15kHz$. We also remark the existence of vibrations during the stick. It is due to the application of the voltage step (from $+150V$ to $-150V$) during the slip mode. On the other hand, the measurement of angular motion shows that the step is about $0.05 \cdot 10^{-4} rad$. In the two cases (linear and angular motions), the amplitudes of the steps are small enough to be compatible with our requirements.

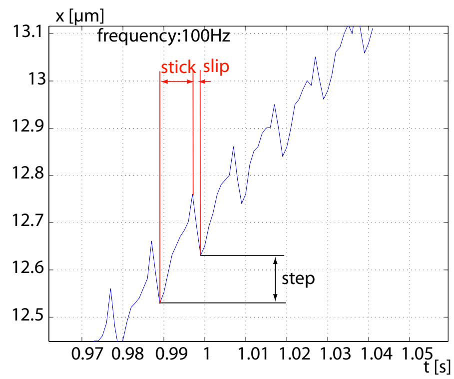

Fig. 4. Measurement of the steps in linear motion : voltage $U = 150V$ and frequency $f = 100Hz$.

B. High stroke experiments

Here, we present the speed performances of the microsystem according to different values of voltage and frequency.

1) Linear motion: Our first measurements in large stroke were to check if the tube defect affects the displacement linearity of the microsystem. The Fig. 5-a shows that the motion of the microsystem along the tube is linear for different frequencies when $U = 150V$. Similarly, for different voltage when $f = 10kHz$, the motion is quasi-linear along the tube (see Fig. 5-b). We conclude that the design is robust relatively to the defect of the tube.

We deduce from Fig. 6-a the speed performances according to the applied voltage. The maximal voltage supported by the microactuators is $160V$. However, between $40V$ and $60V$, dysfunctions appear. Below $40V$, the microsystem can't move. From the figure, we can assume that the speed is nearly linear *vs* the voltage. The spectrum of the speed is shown in Fig. 6-b. We see that at the frequencies $8.5kHz, 14.5kHz, 16kHz$ and $17.5kHz$, there are local minimum. In fact, these frequencies

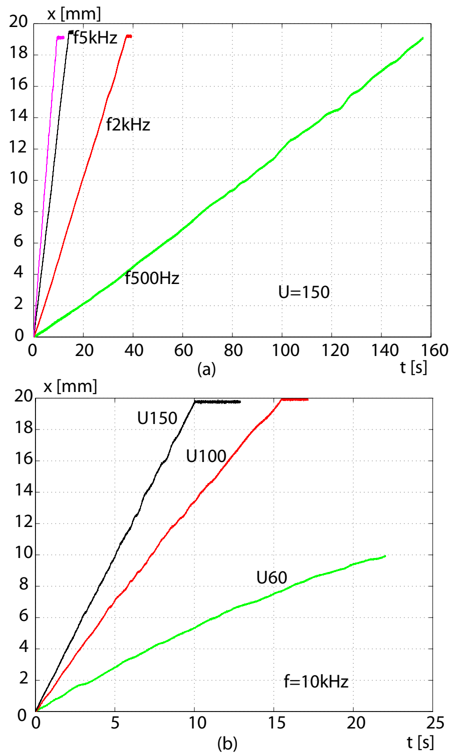

Fig. 5. The linear displacement of the microsystem along the tube is nearly linear. That means that the adaptable spring compensates efficiently the defect of the tube.

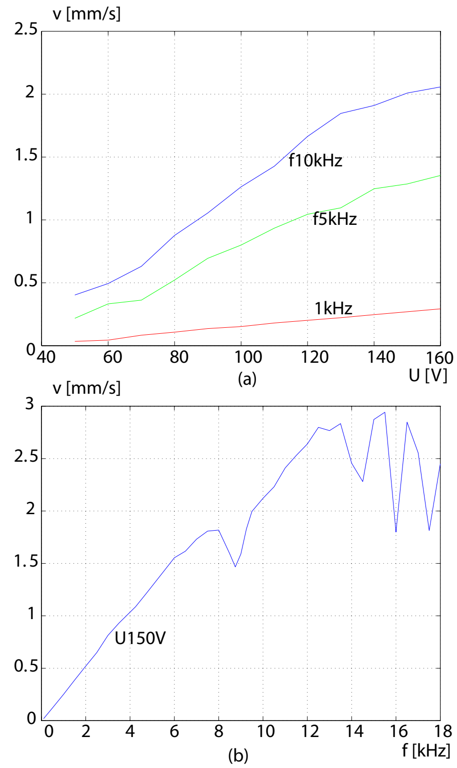

Fig. 6. Performances on speed of the microsystem in linear motion. a : speed *vs* voltages. b : spectrum of the speed.

correspond to natural frequencies of the microactuator and/or the tube. The curve may be divided into two parts.

- The first part is the linear part, from $100Hz$ up to $12kHz$. Except the local minimum, this part may be interesting for closed-loop control using frequency as input.
- The second part is above $12kHz$: saturation and loss of speed appear. This means that above a certain value of frequency, the slope of the voltage is too high and the strain acceleration of the microactuator may generate a force which exceeds the stiction. Some stick phase doesn't appear during the motion.

We notice that the minimum frequency which let the microsystem move is about $0.5Hz$ for a voltage of $U = 150V$.

2) Angular motion: Fig. 7-a shows that the microsystem has a linear displacement around the glass tube even if it presents minor defect of circularity. Fig. 7-b presents the spectrum of the average speed. Similarly to linear motion, we see the diminution of the speed at about $8.5kHz$.

IV. Conclusion

In this paper, the design and the development of a microsystem with two degrees of freedom were presented. The microsystem uses piezoelectric microactuators in stick-slip mode. The steps amplitude varies according to the frequency and the amplitude of the voltages. The maximal step value is $170nm$ in linear motion and $0.05 \cdot 10^{-4} rad$ in angular motion. These values are obtained when the frequency is about $13kHz$. At this frequency, the maximal speeds are obtained ($2.8mm/s$ in linear motion and $0.22rad/s$ in angular motion). The results obtained fulfill the requirements for the system. The next work is to use two microsystems in cooperation on a tube (see Fig. 1) in order to manipulate microparts. After that, closed loop control (force and position) will be studied.

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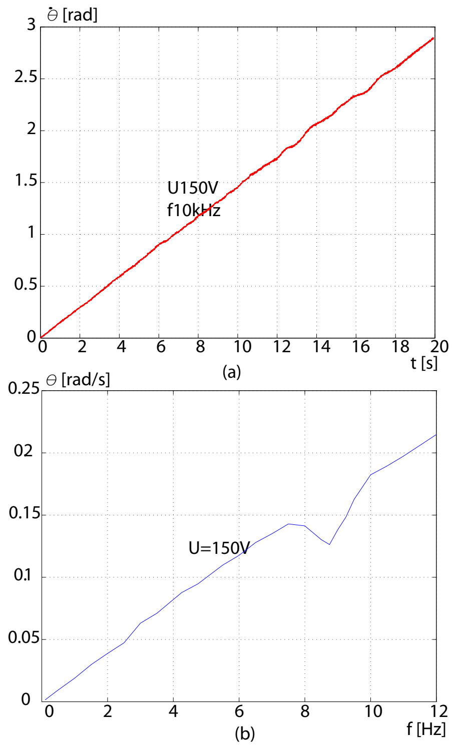

Fig. 7. Characteristic of the angular motion. a : angular displacement of the microsystem for $U = 150V$ and $f = 10kHz$. b : spectrum of the speed for $U = 150V$.

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