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Results on the closed-loop control of the TRING-module dedicated to a modular micromanipulation station

Micky Rakotondrabe, Yassine Haddab and Philippe Lutz
Laboratoire d'Automatique de Besançon - CNRS UMR6596
Université de Franche-Comté - ENSMM
 24, rue Alain Savary
 25000 Besançon - France
 {mrakoton,yhaddab,plutz}@ens2m.fr

Abstract—A new control type for stick-slip microsystems is proposed in this paper: the voltage/frequency (U/f) proportional control. It gives more precise results relatively to the classical control algorithm. It is also an englobalization of two classical controllers: the sign and the classical proportional controllers. A high stroke model of a stick-slip microsystem is first given. Then, we theoretically analyze the performances of the closed loop process with the U/f controller. Finally, we gives some experimental results obtained with different values of the proportional gains.

I. INTRODUCTION

Stick-slip actuators, generally based on piezoelectric materials, are characterized by their simplicity, rapidity, low cost and possibility of batch fabrication. Two modes of motion can be obtained with a micropositioner using stick-slip actuators [1]: the stepping mode and the scanning mode. The stepping mode consists on applying a sawtooth voltages to the micropositioner and let it move step by step, in high range and with a high velocity on the workspace. The resolution in this mode is limited to one step. When the difference between the target position and the present postion becomes less than the value of a step, the legs (piezoelectric actuators) are bent slowly until the final position is reached. This is the scanning mode and the obtained resolution can be very high. It is possible to have a similar resolution in the stepping mode by diminishing the amplitude U of the sawtooth but the vibrations occuring in each steps [2] may influence the performances.

There are two modes of control for stick-slip micropositioners: control in stepping mode for high stroke positioning and control in scanning mode for fine positioning. Each of them may be open-loop or closed-loop structure. This paper deals with the high stroke positioning control in proposing a new type of controller: the voltage/frequency (U/f) proportional controller.

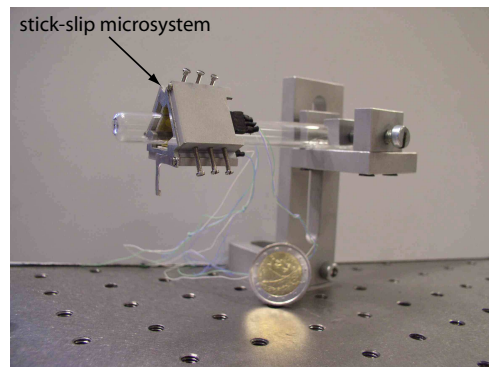


Fig. 1. The stick-slip microsystem.

II. CHARACTERISTICS AND MODEL OF THE MICROSYSTEM

The stick-slip microsystem experimented here is the TRING-module presented in [3]. It has two degrees of freedom (2DoF: linear and angular) but our test will only be performed in the linear motion. The maximal step value of the microsystem is about $300nm$ and the speed can reech $2mm/s$. These are obtained with a sawtooth input voltage of $\pm 150V$ amplitude and $10kHz$ frequency.

Recently, we modeled the stick-slip microsystem in its high stroke motion. The model is as follow:

$$\begin{cases} v = 0 & \text{if } |U| \leq U_0 \\ v = \alpha \cdot f \cdot (U - \text{sgn}(U) \cdot U_0) & \text{if } |U| > U_0 \end{cases} \quad (1)$$

where v is the speed, U and f are respectively the amplitude and the frequency of the sawtooth voltage, $U_0 = 35V$ is the value of U below which the microsystem can't move and $\alpha = 15,652173 \times 10^{-7}$ is a proportional parameter. The model is validated for $f < 12kHz$.

III. U/F PROPORTIONAL CONTROL OF THE MICROSYSTEM

A. Principle

The principle scheme of U/f proportional control is shown in Fig. 2. The saturations avoid the overvoltages and limit the microsystem work inside the linear frequential zone. Let U_s and f_s indicate the saturations respectively used for the voltage and for the frequency. The proportional gains $K_U > 0$ and $K_f > 0$ are to be adjusted like in classical proportional controller.

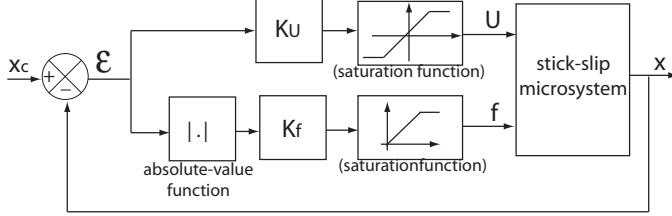


Fig. 2. Principle scheme of the U/f proportional control.

From the Fig. 2 and the formulae (Equ 1), we have the following expression:

$$\dot{x} = \alpha \cdot K_f \cdot |x_c - x| \cdot (K_U \cdot (x_c - x) - \text{sgn}(x_c - x) \cdot U_0) \quad (2)$$

B. Experimental results

The experimental setup is made up of a computer, an amplifier, the microsystem and a laser sensor (resolution $0.5nm$, accuracy $10\mu m$). The computer has no real-time operating system (Windows-XP) and we use LabView software for implementation of the U/f controller.

The choice of K_U is a compromise. If K_U is very low, the static error is high. If K_U is very high, there is a risk of oscillations when the refreshing time T_s is not negligible. For all the experiments, the target point $x_c = 10mm$ and the initial point $x(0) = 0mm$.

The first experiment consist on giving high values of K_u and K_f . They have been choosen so that the phase-2 never happen. The Fig. 3 gives the experimental result and the simulation of (Equ 2). Due to the fact that the operating-system does not have real-time capabilities, the experiment provides oscillations (Fig. 3- in solid plot).

Then, we use a low K_U and a high K_U . The frequency always stays in saturation while the voltage becomes non saturated when $x_c - x$ is inferior to a certain value x_{US} (Fig. 4) such as $x_{US} = U_s/K_U$. After that, the behavior is a voltage proportional control. As shown in the figure, there is a statical error. Its value is equal to $\varepsilon_{stat} = U_0/K_U$.

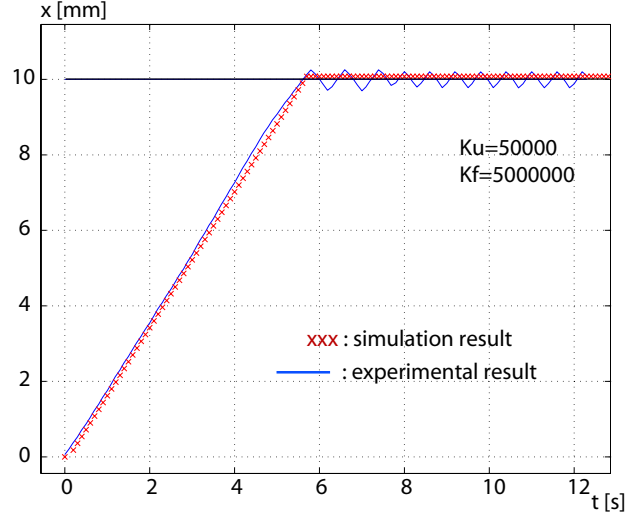


Fig. 3. High values of K_U and K_f : case a).

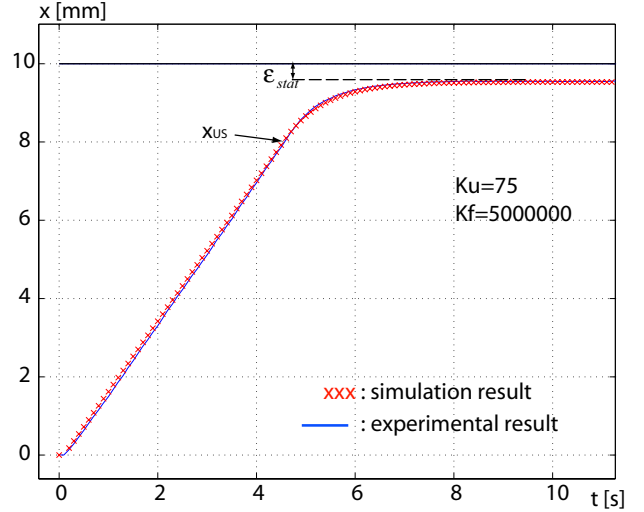


Fig. 4. Low K_U and high K_f .

After that, we experiment with a high K_U but a low K_f (Fig. 5). The leaving saturation speed is obtained at $(x_c - x) = x_{fs} = f_s/K_f$. From this point, the closed loop system has the frequential proportional behavior and there is no statical error.

Finally, we test moderated values of K_U and K_f (Fig. 6). First, the frequency leaves the saturation at $x_{fs} = f_s/K_f$ while the voltage stays saturated. When arriving at $x_{US} = U_s/K_U$, the voltage leaves the saturation. According to the values of K_U and K_f , the inverse circumstance can happens. The statical error is choosen so that $\varepsilon_{stat} = U_0/K_U$.

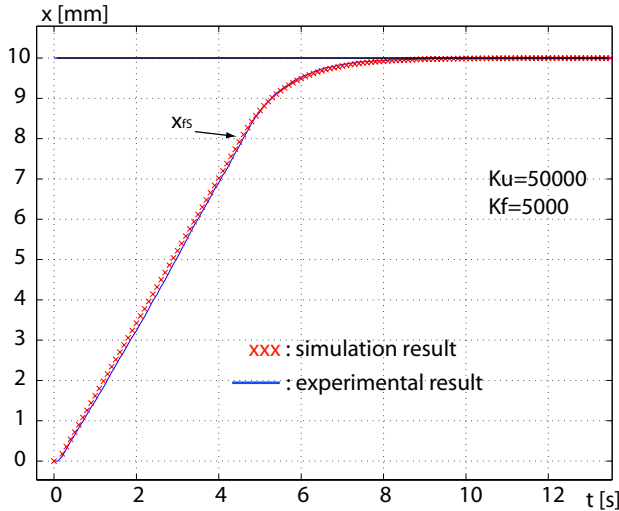


Fig. 5. High K_U and low K_f .

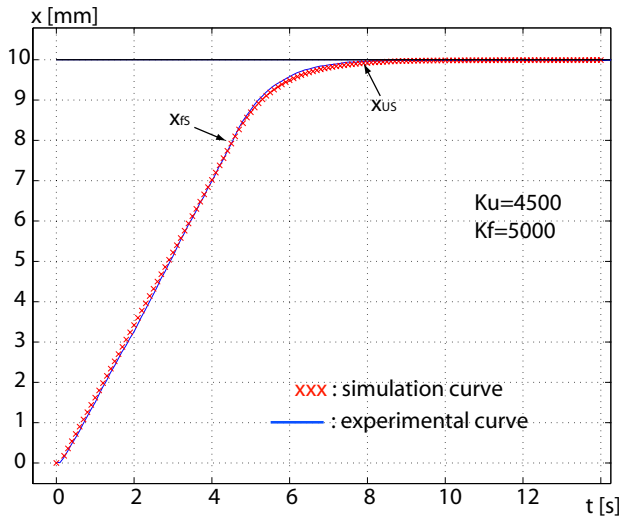


Fig. 6. Decent values of K_U and K_f .

IV. DISCUSSION

The U/f proportional controller encompasses two classical controllers: the sign controller and the classical proportional controller. In comparison with the classical control (closed loop stepping mode), the U/f proportional controller seems to be more precise. The accuracy obtained with this algorithm is one step while the one obtained with the U/f is better than one step, within the limits of the sensor accuracy. In fact, the diminution of the applied voltage $U = K_U \cdot \varepsilon$ reduces of the value of a step. In addition, the diminution of the frequency $f = K_f \cdot \varepsilon$ reduces the number of the steps and then the vibrations.

V. CONCLUSION

This paper has presented the closed loop control of the TRING-module in high stroke. We proposed a new controller type for stick-slip microsystems: voltage/frequency proportional controller. Like a classical proportional controller, it gives a frequency f and an amplitude U which are proportional to the error. The controller has been implemented and the simulation results predicted by the equations fit well to the experiments. The U/f proportional control is a globalization of two classical controllers, the sign and the classical proportional controllers, and it has more resolution than the classical controller of stick-slip microsystems.

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