ID MT-P-029

High Efficiency Driving of Nonresonant Ultarasonic Motor

Koji Kosaka/ Hiroshi Kubota
soh_y@st.cs.kumamoto-u.ac.jp – kosaka@pm-t.com – Kubota+secretary@cs.kumamoto-u.ac.jp
Graduate School of Science and Technology, Kumamoto University
2-39-1 Kurokami, Kumamoto 860-8555, Japan
Phone: +81 -96-342-3035 Fax: +81-96-342-3065

1. Introduction

This paper is focused on piezoelectric actuator for precision stage system which has nano scale resolution. Nanometer order positioning techniques are necessary for semiconductor manufacturing, nanosurgery of biological cells, molecular sensors and the fabrication of quantum devices. Focusing on present semiconductor manufacturing, the featured size challenges the 10nm region. To overcome the further demand for a high throughput and high positioning accuracy, our solution is the nonresonant-ultrasonic motor (NRUSM)[1-4] in contrast of ordinary resonant motor as shown in figure. 1. This figure shows the configuration of NRUSM composed of eight actuators, which work in two groups of legs A and B. Each actuator is stacked with two types of piezoelectric materials, where one expands the leg and the other one shifts the top of the leg. The combination of the phase-different motions of legs A and B feeds a stage over the long distance range. One can use NRUSM as the stage driving device in a SEM chamber, because NRUSM is non-magnetic device. In addition NRUSM is able to be made compact, can be equipped at various miniature tools, for instance, manipulation, pumping, probing systems, having nano scale resolution[5]. NRUSM is also adopted to Reticle Free Exposure(RFE) system which can make the flexible patterning by fine displacing of mask patterns[6].

NRUSM's weak point is the occurrence of a wear because of friction caused by the ultrasonic motor. However this wear can be cut down by reducing the slipping. A previously proven effective solution, by which the driving keeps in the range of static friction without the slipping, results in long life time, high-durability and decrease of particles. We propose two solutions to reduce the slipping: driving method and change of structure. The former is control method using variable frequency instead of constant frequency. The latter is increase of friction tips because static frictional force is proportional to number of the tips.

2. Variable Frequency method

According to our previous research[3], a lot of wear of the guideplate dominantly occurs at the positions of the beginning and/or end of the stage traveling. Therefore, the actuator should drive slowly in the beginning, and increase the speed gradually, and reach the top speed motion, and decrease the speed, and then, stop gently. The variable frequency drive is defined by the frequency as the function of time, because the velocity is in proportional to the frequency in case of no-slipping, as shown in Fig. 2. Fig. 2(a) illustrates the variable frequency profile. Fig. 2(b) shows an actual frequency profile. The profile is characterized by the starting frequency, f_s , the step of the frequency change, Δf_i and step numbers, n_i .

3. Many Friction Points Type Actuator

Static friction actuation is suitable to reduce the slip and abrasion. Static friction actuation must satisfy the equation at t.

$$a_{act}(t) \le -a_{stage}(t)\,, \qquad (1)$$

where a_{act} and a_{stage} are the acceleration values of actuator and stage, respectively. The acceleration value of d^2x/dt^2 at the top of the tip is calculated to be $A\omega^2 \cos\omega t$. a_{stage} permitted under static frictional condition is $k\,\mu N/m$, using the number of friction points k, the static frictional coefficient μ, the normal reaction N and mass of the stage m. Equation (1) is as follows

$$A\omega \cos\omega t \le k\frac{\mu N}{m}\,. \qquad (2)$$

this equation shows static fiction force is proportional to number of the tips. We made some actuators has many friction points and carried out experiment of driving the stage.

4. Result

Experimental result is shown in figure 3 on driving distance of constant frequency and variable frequency drive. We find that the driving distance under variable frequency drive is increased to 17μm. And figure 4 shows experimental result of driving distance at 1 feed on type of actuator has two friction points. We find that the driving distance is increased by 30% in static friction.

[1] Y. Egashira et al.: Jpn. J. Appl. Phys. 41 (2002) 5858.
[2] T. Endo et al.: Jpn. J. Appl. Phys. 44 (2005) 5264.
[3] K. Kosaka et al.: Jpn. J. Appl. Phys. 45 (2006) 1005.
[4] Y. Soh et al.: Proc. of ALC'09 (2009) 357.
[5] F. Imura et al.: Jpn. J. Appl. Phys. 46 (2007) 7519.
[6] Y. Soh et al.: Proc. of TACT (2009).

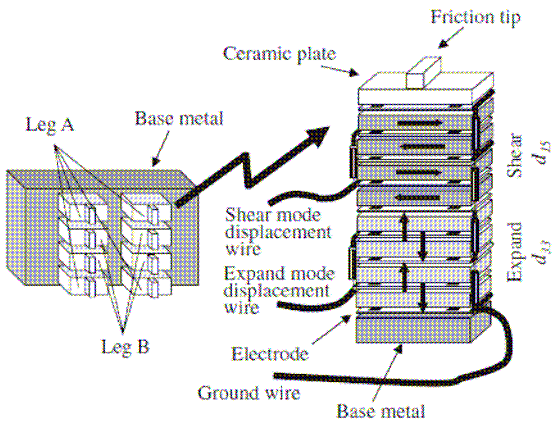


Figure 1. Composition of the NRUSM

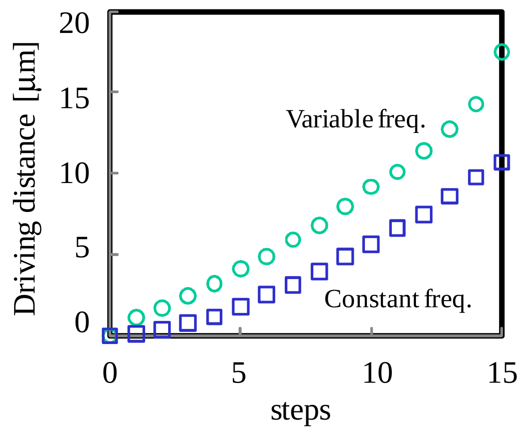
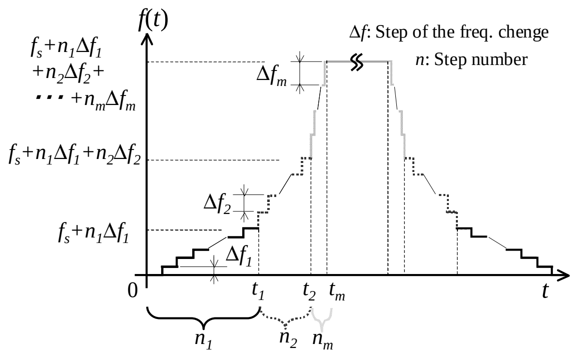
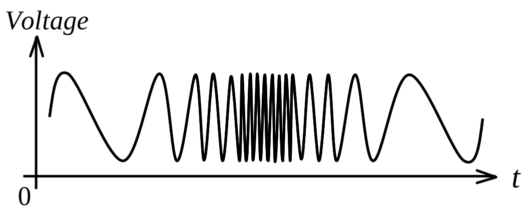


Figure 3. Driving distance of constant frequency and variable frequency drive



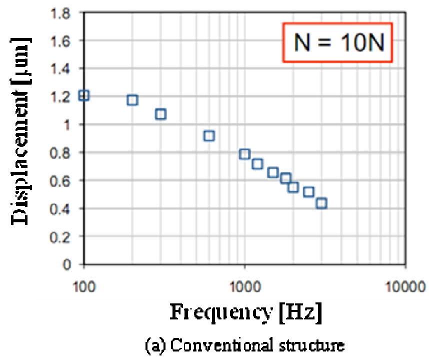
(a)



(b)

Figure 2. Concept of variable frequency drive control

(a) Frequency profile (b) Voltage applied



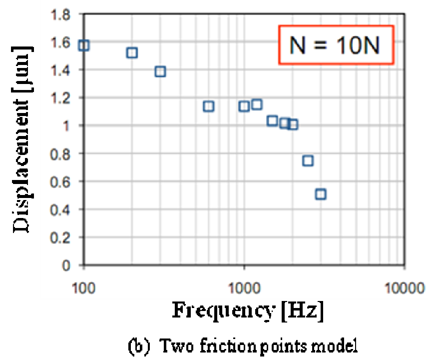


Figure 4. Driving distance of conventional structure and two friction points model
(a) conventional structure
(b) two friction points model