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Controlled Frequency Driving of Nonresonant Ultrasonic Motor for Wear-reduction

非共振型超音波モータの周波数制御低摩耗駆動

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1. Introduction

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 while the featured size challenges the 10nm region. In addition the precision stage is necessary for photomask/reticle inspection system and particle sensing devices. According to the ITRS2009 forecast[1], DRAM with a minimum line width of 32 nm (1/2 pitch) will be manufactured by 2013. To overcome the further demand for a high throughput and high positioning accuracy, our solution is the nonresonant-ultrasonic motor (NRUSM)[2-5] in contrast of ordinary resonant motor classified by using no resonant frequency. **Fig. 1** 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. To control stage driving, ultrasonic actuator has two parameters of voltage amplitude and driving frequency. One can propose three driving methods of variable voltage-amplitude driving method, variable frequency driving one, and those combined driving one. The target point of the driving frequency and voltage, where the stage has maximum speed and non-resonant behavior, could not be obtained under only constant frequency or constant voltage, because the resonant phenomena of higher-orders exist the set of significant points as shown in **Fig. 2**. Ordinary resonant motor under the constant frequency(break line) does not attain to target due to the significant points, but NRUSM(solid line) can avoid the sets by using variable controlled frequency and voltage method[4][5]. In this paper we have focused on the method of the controlled frequency driving with the wear reduction phase.

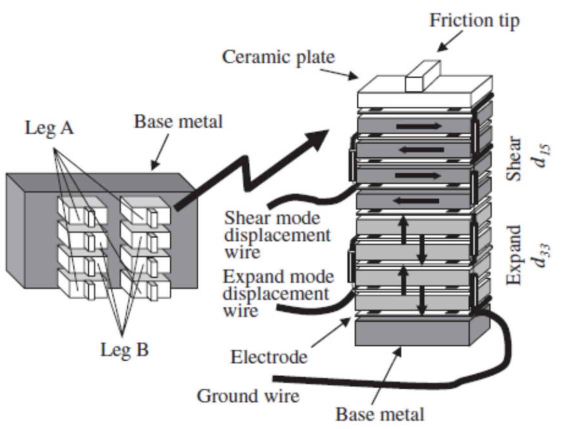

Fig. 1. Composition of the NRUSM

2. Controlled Frequency Driving Method

According to our previous research[4], 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 controlled 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. 3**. Fig. 3(a) illustrates the variable frequency profile. Fig. 3(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 .

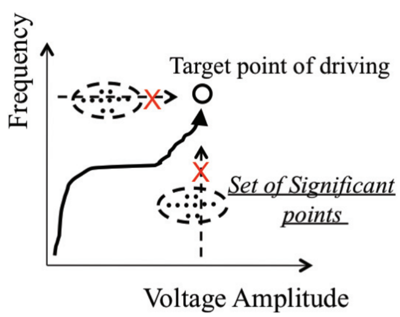

Fig. 2 The target point of the driving frequency and voltage

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3. Physical model

Fig. 4 shows the displacement, the velocity and the acceleration of the tip of the actuators legs A and B as a function of time. At the time, t=0 the tip contacts the guideplate and an initial velocity of the stage is v_0. The behavior of the stage and the actuator as follows: 1) The velocity of the stage (v_{stage}) is accelerated by reaction force of kinetic friction. The tip of the actuator is accelerated by applied voltage. The actuator forereaches the stage at t=t$_c$. 2) Static friction actuation is suitable to reduce the slip and abrasion. According to the reference[3], static friction actuation must satisfy the equation at $t=t_{c1}$.

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

where a_{act} and a_{stage} are the acceleration values of actuator side and stage, respectively. Δf_i of frequency profile were determined by this equation. The acceleration value of d^2x/dt^2 at the top of the tip is calculated to be $A\omega^2 cos\omega t$. And a_{stage} permitted under static frictional condition is $\mu N/m$, using the static frictional coefficient μ, the normal reaction N and mass of the stage m. Therefore, equation (1) is as follows

$$A\omega\cos\omega t_c \leq \frac{\mu N}{m}\,. \qquad (2)$$

and we can calculate the relationship of f_s and Δf using this equation as $\omega_n=2\pi(f_s+\Sigma n\Delta f_n)$ as shown in **Fig. 5**. The wear was reduced by controlled frequency driving method using this relationship.

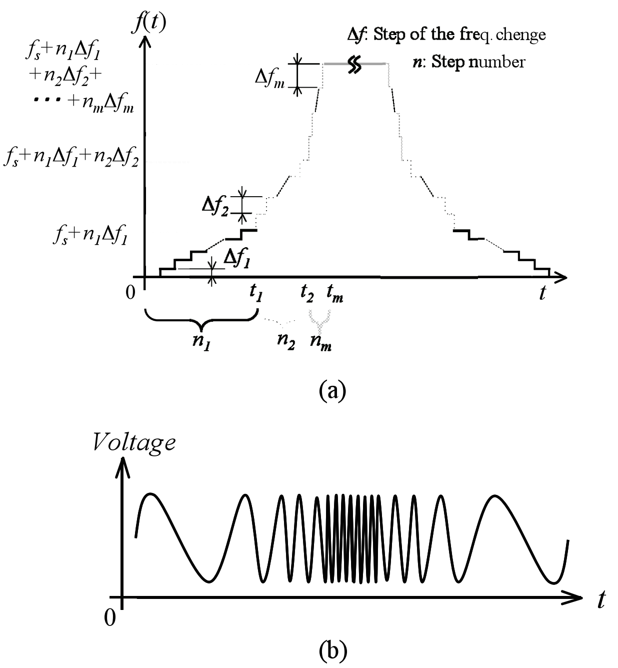

Fig. 3. Concept of controlled frequency driving method
(a) Frequency profile (b) Voltage applied

4. Conclusion

Using controlled frequency driving method, we have improved to reduce the slip and the wear.

In the ultrasonic motor, a lot of wear of the guide plate occured because of beginning movement and turning back especially. According to our results, the actuator should drive slowly, and increase the speed gradually in starting movement. Controlled frequency driving method we propose, has reduced abrasion and optimized the slipping.

References

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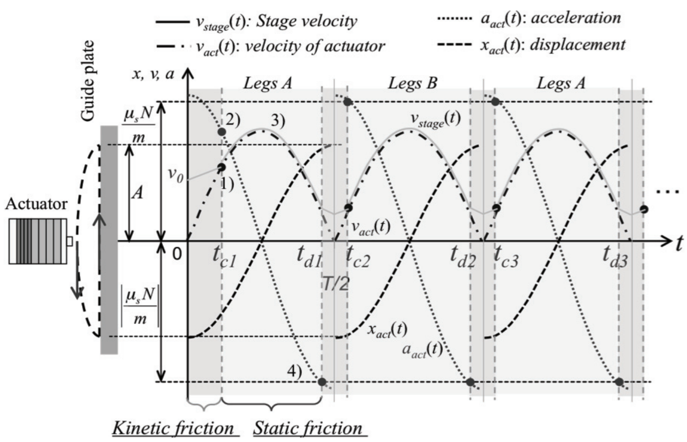

Fig. 4 Physical model of NRUSM

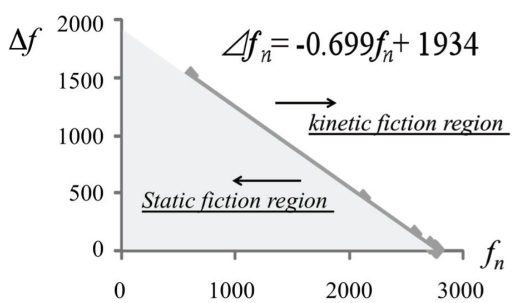

Fig. 5 The relationship of f_s and Δf