Motion profile의 jerk force를 고려한 원자 현미경용 나노스캐너의 진동 제어
Vibration control of nanoscanner considering jerk force of the motion profile for AFM

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Key words : nano scanner, jerk force, motion profile

1. Introduction

Recently, the application areas of nanotechnology are expanding to the various areas such as nanometrology, nanolithography, high density data recording, etc. [1-3]. High precision x, y, and z axes nanoscanner are essential for these applications. Especially, The nanoscanners are required to have large working range, simple structure, reliability and low cost in addition to the high accuracy and high servo bandwidth. The nanoscanner driven by a lead zirconate titanate(PZT) has been conventionally applied to these applications since it provides high resolution and wide bandwidth[4, 5]. The element of PZT is connected to the flexture hinge structure which moves proportionally by the voltage applied to the PZT. Since the actuating force is high enough to drive the flexure hinge, the nanoscanner can be modeled by just mechanical spring without considering the PZT element mass. Hence, the nanoscanner driven by PZT actuator can be considered as a flow source model driven by the velocity of the PZT. Thanks to this velocity input characteristics of the PZT actuator, the PZT driven nanoscanner has no vibration problem even though it has disadvantage of short working range.

The nanoscanner driven by a voice coil motor(VCM) provides large working range as well as a sufficient force to control the nanoscanner with a high speed[6, 7]. The VCM nanoscanner is usually composed of permanent magnets, electromagnets and flexure hinge structure. Using the Lorentz force generated between the permanent magnets and electromagnets, the flexure hinge structure can move proportionally to the applied current. Hence, it can be considered as a second order system composed of mass and spring driven by the electromagnetic force. Due to this characteristics, the VCM scanner causes mechanical vibration when the control input signal is near to the resonance frequencies of the nanoscanner. In order to expand the nanoscanners to the industrial application purposes with high precision such as AFM, it is necessary to design them which has a large working range and little vibration problem. There is an effort to amplify the displacement for the PZT driven nanoscanner using a mechanical displacement amplifying structure such as [8, 9, 10]. However, this structure requires additional mass and spring which is not modeled any more as a flow source model but an effort source model. The same vibration resonance problem is occurred as in the VCM nano scanner.

Movement of the nanoscanner with trapezoidal point-to-point motion profile such as in atomic force microscopy (AFM) can cause a nano level vibration. The sudden change of the input command will result in a large jerk to the mass-spring scanning system[11, 12]. When the frequency of the input command is near to the resonance frequency of the nanoscanner, it causes vibration which reduces the servo bandwidth as well as the accuracy of the AFM image of the samples.

In this paper, the motion profile of the VCM nanoscanner is proposed to reduce the undesirable frequency response characteristic of the VCM nanoscanner. It employs the proposed motion profile generation approach to minimize the jerk force applied to the VCM nanoscanner. The simulation results of the jerk force of the proposed motion profile and fast fourier transform(FFT) are presented. To verify the performance of the designed motion profile, we measure the time responses of the VCM nanoscanner and check the FFT results of the time response of the VCM nanoscanner.

2. Design of the motion-profile

We propose an vibration-free motion profile to solve the vibration problem. The purpose of this method is to minimize the jerk force in high-speed, high-precision motion control. As jerk force is proportional to the derivate of acceleration, so the basic idea is to reduce the acceleration and the change rate of the acceleration at the start and stop motion of the nanoscanner. The normalized poly-nominal equation of the displacement profile is represented in equation (1). Equation (2), (3) and (4) show the normalized poly-nominal equation of velocity profile, acceleration profile and jerk profile.

$$y(\frac{t}{T}) = [a + b(\frac{t}{T}) + c(\frac{t}{T})^2 + d(\frac{t}{T})^3 + e(\frac{t}{T})^4 + f(\frac{t}{T})^5 + g(\frac{t}{T})^6 + h(\frac{t}{T})^7]S \qquad \text{Eq. (1)}$$

$$\dot{y}(\frac{t}{T}) = [b + \frac{2c}{T}(\frac{t}{T}) + \frac{3d}{T}(\frac{t}{T})^2 + \frac{4e}{T}(\frac{t}{T})^3 + \frac{5f}{T}(\frac{t}{T})^4 + \frac{6g}{T}(\frac{t}{T})^5 + \frac{7h}{T}(\frac{t}{T})^6]S \qquad \text{Eq. (2)}$$

$$\ddot{y}(\frac{t}{T}) = [\frac{2c}{T^2} + \frac{6d}{T^2}(\frac{t}{T}) + \frac{12e}{T^2}(\frac{t}{T})^2 + \frac{20f}{T^2}(\frac{t}{T})^3 + \frac{30g}{T^2}(\frac{t}{T})^4 + \frac{42h}{T^2}(\frac{t}{T})^5]S \qquad \text{Eq. (3)}$$

$$y'''(\frac{t}{T}) = [\frac{6d}{T^3} + \frac{24e}{T^3}(\frac{t}{T}) + \frac{60f}{T^3}(\frac{t}{T})^2 + \frac{120g}{T^3}(\frac{t}{T})^3 + \frac{210h}{T^3}(\frac{t}{T})^4]S \qquad \text{Eq. (4)}$$

where S is working range of the nanoscanner, T is working time and t is an arbitrary time instant. a, b, c, ...h are the coefficients of the poly-nominal equation. The eight constant are can be determined using the eight boundary conditions expressed as

$$\begin{aligned} &y(0) = 0, \quad y(1) = 1 \\ &y'(0) = 0, \quad y'(1) = 0 \\ &y''(0) = 0, \quad y''(1) = 0 \\ &y'''(0) = 0, \quad y'''(1) = 0 \end{aligned} \qquad \text{Eq. (5).}$$

The poly-nominal equation of displacement, velocity, acceleration and jerk are

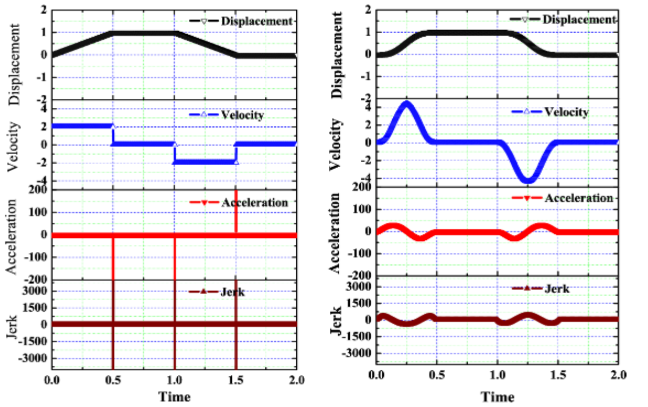
$$y(t) = [35t^4 - 84t^5 + 70t^6 - 20t^7]S \qquad \text{Eq. (6)}$$

$$y'(t) = [140t^3 - 420t^4 + 420t^5 - 140t^6]S \qquad \text{Eq. (7)}$$

$$y''(t) = [420t^2 - 1680t^3 + 2100t^4 - 840t^5]S \qquad \text{Eq. (8)}$$

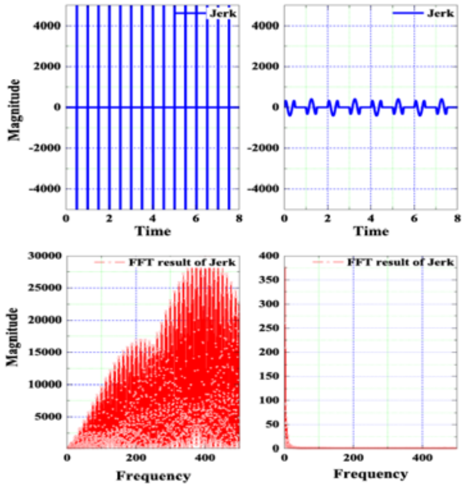
$$y'''(t) = [840t - 5040t^2 + 8400t^3 - 4200t^4]S \qquad \text{Eq. (9)}$$

Figure 1 (a) shows the displacement, velocity, acceleration and jerk profile of trapezoidal point-to-point motion. A schematic view of the developed displacement, velocity, acceleration and jerk profiles is shown figure 1 (b). Simulated fast fourier transform (FFT) results of the trapezoidal point-to-point motion profile and proposed motion profile show in figure 2 (a) and 2 (b).



(a) (b)

fig. 1 simulation results of displacement, velocity, acceleration and jerk (a) trapezoidal point-to-point motion profile, (b) proposed motion profile



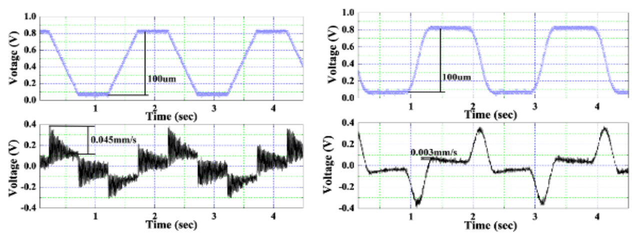
(a) (b)

fig. 2 simulated fast fourier transform (fft) results of the jerk (a) trapezoidal point-to-point motion profile, (b) proposed motion profile

Comparing the simulation results of trapezoidal point-to-point motion profile with the proposed motion profile, we can see that the acceleration and jerk are infinite in the trapezoidal point-to-point motion profile, however, they are decreased at the start and stop point of the proposed motion profile. Moreover, the fft magnitude of the proposed motion profile is much smaller at the resonance frequency of the VCM nanoscanner, about 75Hz.

3. Experimental results

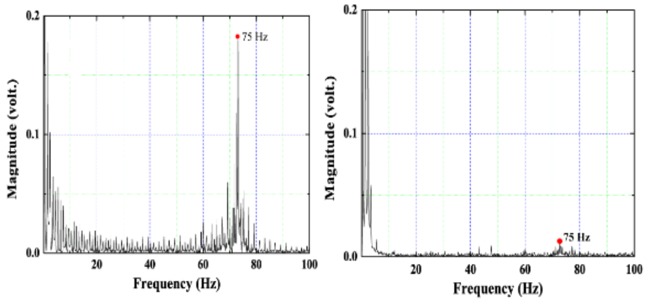
Figure 3 show the applied motion profile to the VCM nanoscanner and its time response. Figure 3 (a) shows the vibration is induced at the start and stop points of the trapezoidal point-to-point motion profile. Then, the maximum magnitude of the measured vibration (△) is 0.045 mm/s. Figure 3 (b) shows the vibration is almost reduced at the start and stop point of the proposed motion profile. The maximum vibration (△), 0.003mm/s is decreased to over 90 percentage.



(a) (b)

fig. 3 The measured vibration of the VCM nanoscanner (a) using the trapezoidal point-to point motion profile, (b) using the proposed motion profile

Figure 4 (a) shows fast fourier transform result of the measured vibration when the trapezoidal point-to-point motion profile is applied to the nanoscanner. We can check the frequency of the vibration is same as the first resonance frequency of the VCM nanoscanner, 75 Hz. However, the vibration is almost reduced when the proposed motion profile is applied as shown in figure 4 (b).



(a) (b)

fig. 4 The FFT results of the measured vibration (a) using the trapezoidal point-to-point motion profile, (b) using the proposed motion profile.

4. Conclusion

In order to solve the vibration problem of the VCM driven actuator for SPM applications, the 7th order point-to-point motion profile is applied with the consideration of the smooth the force applied to the VCM nanoscanner which results in a smoother jerk force. The vibration problem is disappeared in the experimental results as seen in the time domain and FFT results. .

The VCM nanoscanner can be expanded for use to the application for the large working range and control without using the external sensor and reasonable working speed range to the resonant frequency of the nanoscanner.

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