A Novel Trans-Scale Precision Positioning Stage Based on the Stick-Slip Effect

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ABSTRACT

This article focuses on developing a novel trans-scale precision positioning stage based on the stick-slip effect. The stick-slip effect is introduced and the rigid kinematics model of the stick-slip driving is established. The forward and return displacement equations of each step of the stick-slip driving are deduced. The relationship of return displacement and the acceleration produced by friction are obtained according to displacement equations. Combining with LuGre friction model, the flexible dynamics model of the stick-slip driving is established and simulated by using Simulink software. Simulation results show that the backward displacement will reduce with the acceleration of the slider produced by dynamic friction force, the rigid kinematics model is also verified by simulation results which are explained in further detail in the article.

Keywords: Nanotechnology, Precision Positioning, PZT Actuator, Stick-Slip Driving, Trans-Scale

INTRODUCTION

As a main research direction of nanotechnology, nanometer positioning technology has already attracted substantial attention (Breguet, Driesen, Kaegi, & Cimprich, 2007; Sitti, 2001). The precision positioning stages with nanometer positioning accuracy have already been extensively applied to many important engineering realms, such as MEMS (Cahyadi & Yamamoto, 2006; Chung, Choi, & Kyung, 2006; Zhang, Hesselbach, & Kerle, 2006), bioengineering (Ishii, Ishijima, & Yanagida, 2001), medical engineering (Yamamoto et al., 2000), optics engineering and aerospace engineering (Saeidpourazar & Jalili, 2008), etc.

In most of positioning operations are directly driven by PZT actuators. The PZT actuator needing to extend 100 microns commonly own 100 millimeters in length (Fleming & Leang, 2010). The PZT actuator isn’t suitable for the tight space application directly and cannot carry out movement in larger range. Many research efforts depended on nanometer positioning
technology have been greatly restricted by the movement in small scope. Trans-scale precision positioning means that a technology has nanometer resolution and micrometers movement range (Jang, Lee, & Choi, 2008; Li et al., 2011). Therefore, trans-scale precision positioning stage has become the key technique in nanometer positioning methodology and requiring research efforts and attention.

At present, trans-scale precision positioning technology is divided into four types of driving methods. They are macro-micro hybrid driving (Gloess, 2006), piezoelectric ultrasonic driving (Holmes, Hocken, & Troumper, 2000), inchworm-type driving (Roh & Kwon, 2004) and slip-stick driving (Bergander, Breguet, Schmitt, & Clavel, 2000; Edeler & Fatikow, 2011). The frontal three driving methods can carry out trans-scale movement and have high resolution, but because of their complicated structures and control, they cannot be applied in many nano-manipulation mechanisms in tight and contained space. Slip-stick driving as a new trans-scale technique has a great deal of advantages, such as large range movements, high resolutions, simple structures, small size and precision positioning. Because of its small structure and easy precision position, slip-stick driving own extensive applied foreground.

The driving method and movement model of slip-stick driving have important theoretical significance and practical values. Based on such research, a novel trans-scale precision positioning stage using the stick-slip effect was developed. Stack PZT was used in the novel stick-slip precision positioning stage and applied in the trans-scale precision positioning operations, enabling the development of precision positioning methodology.

**PRINCIPLE RESEARCH**

The stick-slip driving is a typical drive mode based on the theory of the friction (Brufau et al., 2005). The essence of stick-slip driving is executed by the difference between friction force and impulsive force. The driving method can be divided into stepping-mode and scanning-mode (Arvid, 2003). In the stepping-mode, each step consists of a slow deformation of the PZT followed by an abrupt jump backward (Meyer, Sqalli, Lorenz, & Karrai, 2005). During the slow deformation the stage follows the PZT because of friction (stick), whereas it cannot follow the sudden jump because of its inertia (slip). The step frequency and the amplitude are decided by the frequency and the amplitude of voltage driving signal. The stepping-mode allows long displacements at a relatively high speed (typically 2mm/s). The resolution is limited by the displacement of a step. In the scanning-mode, the position of the stage is within less than a step distance from the target, the PZT are deformed slowly until the final position is reached. The resolution is a fraction of a step (typically better than 5nm).

The driving principle of the stick-slip stage is shown in Figure 1. The stage basically consists of three parts: the slider, the PZT actuator and the inertial mass. The sawtooth wave as shown in Figure 1 is the driving signal when the stick-slip stage is worked.

In the first step, without driving signal, the PZT actuator has no deformation and the inertial mass and slider remain static. In the second step, for obtaining a net step, the PZT actuator firstly accelerates very rapidly over a short period of time (typically microsecond $\Theta \rightarrow \Theta_2$) so that the inertia of the slider overcomes the friction between slider and inertial mass. This way, the slider disengages from the accelerated inertial mass and remains nearly fixed. In this step, the distance between the slider and the inertial mass is $\Delta X_1$. This step can be named as slip step.

In the third step, the PZT takes the inertial mass moving back to its initial position slowly enough so that the slider sticks to it, and thus makes a net displacement $\Theta_2 \rightarrow \Theta_3$. Periodic repetition of this sequence leads to a step-by-step motion of the slider in one direction. A PZT actuator pushes or pulls the inertial mass, the exact sequence in the slip and stick motion is controlled by an appropriate voltage signal.
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