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

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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 position-
ing 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 (typi-
cally 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 bet-
ter 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 iner-
tial mass and slider remain static.

In the second step, for obtaining a net step,
the PZT actuator firstly accelerates very rap-
idly over a short period of time (typically micro-
second ①→②) so that the inertia of the
slider overcomes the friction between slider
and inertial mass. This way, the slider disen-
gages 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 (②→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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