Novel Nanometer precision Planar Positioning stage using Pre-sliding friction

Paul Ouwehand
Introduction
Introduction

Electron microscopy

- Scanning electron microscopy (SEM)
- Positioning stage
- Nanometer precision
Introduction

Positioning stage

• Specifications:
  • Coarse stage: 10x10 mm
  • Fine stage: 4x4 μm

• Steps:
  1. Coarse positioning
  2. Fine positioning
  3. Scan
Introduction

Sliding stage

- Two stage → one stage
- Teflon sliding stage
- Friction → nanometers?
Pre-sliding

- Apply force below static friction limit

**Graph 1:**
- Pre-sliding displacement due to a constant force

**Graph 2:**
- Static friction limit
Introduction

Goals

1. Pre-sliding positioning
   - nm resolution
   - Smooth: easy to control
   - Predictable: feedforward

2. Nanometer planar stage
   - Less complex
   - Compact
   - Stability
Pre-sliding

What is pre-sliding?

- Adhesive forces resist motion

- Elastic and plastic deformation of contact
  - Slow (<1 μm/s)
  - Infinite displacements
Pre-sliding
Elastic + plastic

- Elastic part
  - Linear

- Plastic part
  - Non-linear (F)
  - Non-linear (x)

- Spring + damper model

![Graph showing pre-sliding displacement due to a constant force with different forces (0.10 N, 0.15 N, 0.20 N, 0.22 N). The graph shows elastic deformation, plastic deformation, elastic unloading, and relaxation over time.]
Pre-sliding

Pre-sliding vs full-sliding

- Pre-sliding
  - Stable

- Full-sliding
  - Unstable

- Force controlled

Introduction - Pre-sliding - Concept - Design - Controller - Results - Conclusions
Concept

Overview

• Requirements:
  1. Range: 10x10 mm
  2. Resolution: 1 nm
  3. Tracking: 10 nm/s
Design

Preview
Design

Contact points

• 3 contact points
• Equal normal force
• Sphere-to-plane
• 30 μm Teflon coating
Design

Mover

- 100x70 mm
- No wires attached
**Design**

**Actuator**

- Lorentz actuators
- Current amplifier
- Magnets on mover
Design

Sensors

• Planar:
  • 2D encoder

• Rotational:
  • optical sensor
Design

Overview

Actuator coils integrated in PCB

2D encoder head

Contact points

Rotational sensor

Teflon coated sphere
Controller

Overview

• Position feedback
Controller

Control structure

Introduction - Pre-sliding - Concept - Design - Controller - Results - Conclusions
Results

Positioning controller

- Two-step controller
- nm resolution
- With/without holding force
Results

Tracking controller

- $v = 10 \text{ nm/s}$
- $x_{\text{tot}} = 200 \text{ nm}$
- $\epsilon_{\text{max}} = 10 \text{ nm}$
Results

Tracking controller

- 10 Hz bandwidth sufficient
- Feedforward model reduces tracking error

![Tracking error graphs](image)
Results

Tracking controller

• Infinite displacements!
Conclusions

✓ • New approach positioning using friction

✓ • New concept for nanometer stage

✓ • Low bandwidth suffices 10Hz

✓ • Feedforward improves tracking performance
Recommendations

- Alternative material combinations
- Extended control
Novel Nanometer precision Planar Positioning stage using Pre-sliding friction

Paul Ouwehand