Proceedings of Mechanical Engineering Research Day 2015, pp. 59-60, March 2015

Precision control performances of a vertical motion electrostatic actuator stage with locking function

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Keywords: Multilayer electrostatic actuator; locking function; vertical motion stage.

ABSTRACT – The paper validates the effectiveness of the characteristic switching for a vertical motion electrostatic actuator stage with a holding function. The friction forces often deteriorate the response and positioning accuracy of a control system, especially when the lightweight electrode layers in the electrostatic actuator are supported by only lubricating oil. However, the contact condition between the electrodes can be changed by the attractive forces resulting from the driving signal waveforms. In this paper, the driving signal waveforms for switching between two frictional conditions are examined and clarified. The actuator exhibits a positioning error of less than 14 nm.

1. INTRODUCTION

In microscope systems, optical systems and semiconductor manufacturing systems [1]; high response and high positioning accuracy are critical. In microscope systems, samples need to be finely positioned and precisely held in vertical stages for precision motion. Additionally, in micro electric discharge machining large thrust capability and high positioning and tracking accuracy is desired with use of a clamping mechanism with force magnifying structure as a locking function [2].

As a resolution, an electrostatic actuator supported by only lubricating oil has been proposed in this paper that has a locking function without any additional mechanism. The electrode layers of the actuator are lightweight enough to maintain the gap and reduce the frictional force between the layers without applying voltage. In the actuator, the motion characteristics depend on the driving signal since the frictional force is changed by the driving signal. The frictional force exhibited by the electrostatic actuator is used to continuously generate the holding force, which acts as a locking mechanism. The driving signal waveforms for adjusting two types of frictional force have been proposed; i.e. (a) high friction force for the limited working range motion with a large holding force and (b) low friction force for full working motion. Therefore, in this paper, the usefulness of the electrostatic actuator supported by lubricating liquids with a locking function is demonstrated using a vertical motion stage which uniquely contributes to the research originality.

2. VERTICAL MOTION STAGE STRUCTURE

The electrostatic actuator presented in this paper is a variable-capacitance motor type actuator that has two mover layers. Figure 1 shows the structure of the experimental two-layer electrostatic actuator in the vertical stage. To realize bidirectional motion, voltages V_1 and V_2 are applied to Stator A and Stator B, whilst voltage V_3 is set to zero and applied to the mover shown in Figure 2. Stator B is set to be shifted by 500um to Stator A. Table 1 shows the detail specifications of the electrostatic actuator.

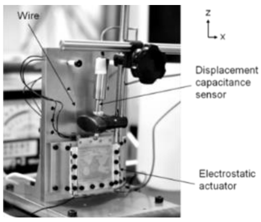

Figure 1 Overall view of the displacement measurement setup in vertical stage.

Table 1 Specifications of the electrostatic actuator.

Parameters	Value
Electrode width and length (mm)	50 × 50
Spacer (mm)	50 × 6.5
Electrode thickness (mm)	0.1
Spacer thickness (mm)	0.4
Mover mass (g)	5.43

In comparison to the horizontal stage [3], the stator is aligned and screwed parallel to the z- axis and spacers are inserted between the stator electrode layers to maintain the gap at each side. Extra film at each side of the laminated stator electrodes is used for fixing the electrode layers of the stator to the base in order to prevent the thin electrodes from bending. The electrodes are laminated with 30μm thickness low density polyethylene flat films as isolation films to reduce the friction between the electrode layers. The lubricating liquid is expected to easily be maintained between the electrode layers using high wettability film in the vertical setup. The nominal silicone oil thickness inserted in the gap is 0.123mm. Figure 2 shows the driving procedures.

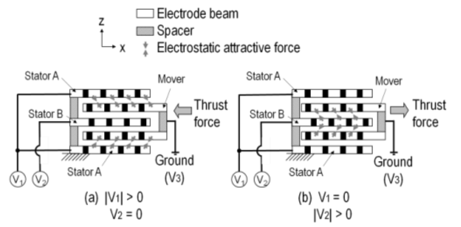

Figure 2 Driving procedures for the bi-directional motion of the electrostatic actuator [3].

3. CONTROL PERFORMANCES WITH LOCKING FUNCTION

In the vertical motion stage, the attractive forces resulting from the driving signal greatly influence the contact condition between the electrode layers (i.e., the frictional effect). The attractive force between the electrode layers causes the mechanical contact which increases the frictional force between them. Although the frictional force deteriorates the positioning characteristics, it is useful as a locking function in the actuator. In order to utilize the characteristics, two driving modes has been proposed and the driving signal profiles for adjusting the frictional effect have been discussed; i.e. (a) fine driving mode for the fine motion with a large holding force and (b) wide driving mode for wide and fast motion. Figure 3 shows the reciprocating motion using applied voltage 1.5kV and the control period, T_{cs}=0.5 ms with the 1kV holding signal.

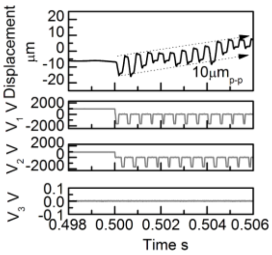

Figure 3 Reciprocating motion characteristics with negative monopulse signal, 1.5kV & 1kV holding signal.

The negative monopulse signal with a duty cycle of 1/5 is used to avoid an increase in the frictional effect and also to ensure the full working range of the actuator. In this paper, the full working range is referred to as the wide working range. The signal is used as the wide driving mode signal to ensure the full working range of the actuator. In order to demonstrate the effectiveness of the electrostatic actuator, the control performances are evaluated. In the vertical setup, gravity will affect motion of the actuator. To maintain the mover position with precision at the desired position, the holding function is vital for that purpose especially during the performance evaluation in the wide motion range. The combination of the wide driving mode and the fine driving mode which is referred to as the dual driving mode is used. The control system was designed based on a PID controller shown in Figure 4. The effect of mass changes on control performances are evaluated as shown in Figure 5.

The vertical motion stage is influenced by the gravity through the movable mass. To evaluate the effect of mass changes, the extra mass of 1.00 g, 2.05 g and 3.12 g is added to the mover. From Figure 5, it can be depicted that the dual driving mode is able to hold the mover with a residual vibration less than 14nm when the mass of the mover increases by 57%. The increased in the mass will increase the positioning time of the actuator; however the mover is still able to be held with precision.

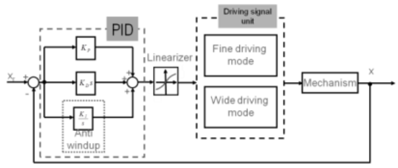

Figure 4 Block diagram of the control system for the dual driving mode

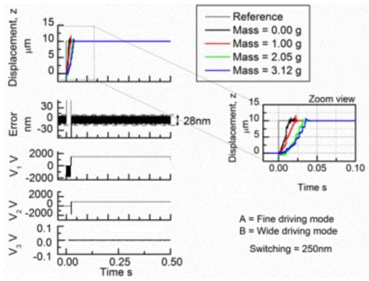

Figure 5 Effect to mass changes using a 10 μm step input under the dual driving mode with 1kV holding signal.

4. CONCLUSIONS

In summary, this paper validates the effectiveness of the holding function for a vertical stage electrostatic actuator maintained by lubricating liquid, which are the main contributions of this paper. In the vertical motion stage, the holding function is crucial for maintaining precise motion due to the influence of gravity.

5. ACKNOWLEDGEMENT

This research and publication is supported by Universiti Teknikal Malaysia Melaka (UTeM) Short Term Grant no. PJP/2013/FKE(4C)/S01170 and Tokyo Institute of Technology, Japan. Authors are grateful to Tokyo Tech. and UTeM for supporting the research.

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