Displacement of a 6-DOF inchworm-based parallel kinematic stage

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Abstract

A novel inchworm-based positioning stage with large motion ranges for microscopes and machine tools is presented. Performance of the stage related to control signal is described. We discuss parasitic motions, which are the displacement orthogonally to the motion plane. The control signal, which reduces the parasitic motions, is determined. The result obtained in this paper is useful for continuous path control and the position and orientation control of the stage.

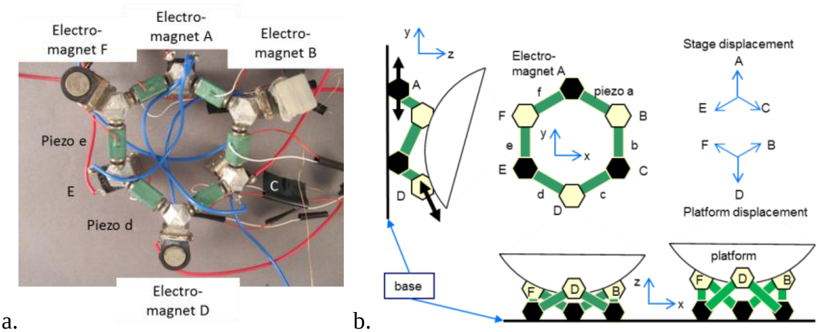
1 Introduction

Recent machine tools require high capability for the ultrafine machining machines and for micro/nano positioning. In order to achieve high resolution, piezoelectric actuators (piezos) are used. Multi-axis machining of surfaces requires not only precision position control but also precision orientation control. We described the concept and design of a six-degree-of-freedom (6-DOF) micro parallel kinematic stage for multi-axis positioning[1]. The stage realized about 10 nm linear displacement. Since the stage was driven by the principle of an inchworm, the stage showed the parasitic motion, which is the displacement orthogonally to the motion plane. In this paper, we discuss the control signal, which reduces the parasitic motions of the stage.

2 Structure of Six-DOF Stage

Figure 1 shows the 6-DOF parallel kinematic stage. Six stacked-type piezos and six electromagnets are used. The proposed 6-DOF stage is based on the hexapod structure. Six metal parts bond the piezos in 109.5 degrees. The stage does not have a fixed base, therefore it has a large motion range on a surface. Three electromagnets A, C, E touching on the base can connect/disconnect the stage and the base. The other three electromagnets B, D, F supporting the platform can connect/disconnect the stage and the platform. The non-excited electromagnets move sequentially by the deformation of the piezos. The stage moves in six directions (x, y, z, θ_x, θ_y and θ_z), realizes sub-micron preciseness, and has an unlimited working area.

The piezo, which is 10 mm in length, deforms 5 μm when 100 V_{DC} is applied. The electromagnetic force is about 5 N when 10 V is applied. The electromagnets and piezos are controlled synchronously, and they rotate and tilt a hemispherical platform. The size of the stage is about 50 mm by 50 mm and 50 mm in height, which depends on the dimensions of the piezos and electromagnets. A platform used in the experiment is a 100 mm square iron flat plate with 1 mm thick.



a. b.

Figure 1: (a) Photo of the 6-DOF stage and (b) schematic diagram of the stage.

3 Control of Six-DOF Stage

3.1 Inchworm motion

In our previous work, the control signal for the stage is based on the principle of an inchworm. Although the principle of an inchworm helps overcome the problem of poor working range, it causes the parasitic displacement. While five out of six electromagnets are excited, the other electromagnet that is not excited moves by the deformation of the piezos. The piezos deform in the longitudinal direction, and thrust the electromagnet. The electromagnet A, C, E move on the base, and the electromagnet B, D, F move on the platform.

In Figure 2(a), voltages applied to the electromagnets and piezos are illustrated. One control cycle is 1 s. The stage connected with a platform by the electromagnets B, D, F moves in horizontal y-direction. Non-excited electromagnets A, C, E sequentially move by the deformation of two piezos. The voltage applied to the piezo is ramp input and the maximum voltage is 100 V. The constant value of the maximum voltage applied to the piezo causes the parasitic motion of the stage. Figure 2(b) shows the horizontal y-displacement and parasitic vertical z-displacement of the platform. Although the horizontal displacement for 10 cycles is about 50 μm, the parasitic displacement in z-direction is 7.5 μm.

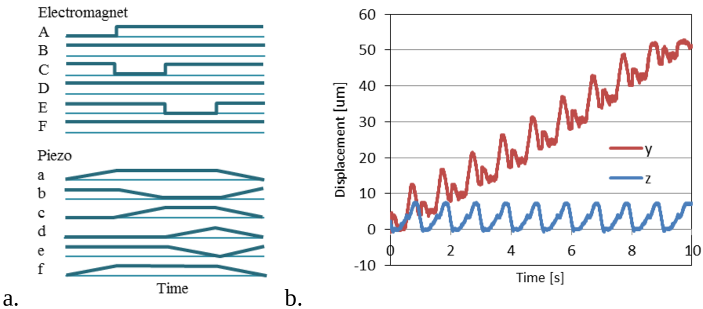


Figure 2: (a) control signals applied to electromagnets and piezos for horizontal displacement and (b) horizontal y-displacement and vertical z-displacement.

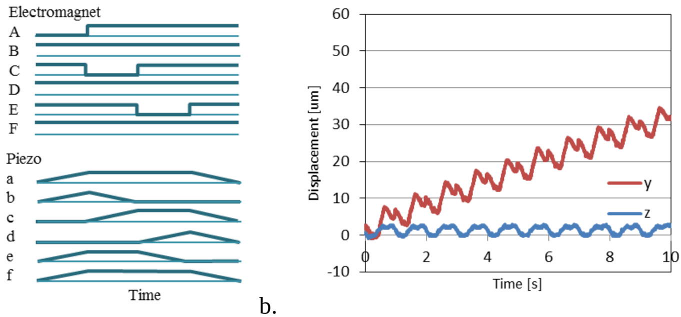
3.2 Control Signal Using Inverse Kinematics

The control signal proposed in this paper is determined by the inverse kinematics. The deformations of the piezos a, b, ..., f are expressed by dL_i (i=1, 2, ... 6), respectively. The deformation of the piezo $dL=\{dL_1, dL_2, dL_3, dL_4, dL_5, dL_6\}^T$ is expressed by

$$dL=J\,dq, \tag{1}$$

where $dq=\{dx, dy, dz, d\theta_x, d\theta_y, d\theta_z\}^T$ denotes the minute displacement of the platform, and J denotes a 6x6 Jacobi matrix which is obtained from the geometrical consideration. The voltage applied to the piezo, which is ramp input, is determined by equation (1). In our experimental setup, a personal computer generates a control signal, which is applied, to the piezo through a voltage amplifier.

Figure 3(a) shows the modified control signals which are used for horizontal y-displacement of the stage. The deformation of the piezo is calculated by the inverse kinematics. The voltage applied to the piezo is determined under the assumption that the deformation of the piezo is proportional to the applied voltage, although the maximum voltage applied to the piezo is 100 V. The speed of the piezo deformation varies according to the voltage applied. Figure 3(b) shows the horizontal y-displacement and vertical z-displacement. By changing the control sequence and the amplitude of the voltage applied to the piezo, the parasitic z-displacement is reduced to 2.7 μm, although the horizontal y-displacement for 10 cycles is also reduced to 32 μm. The fine motion is obtained by the inverse kinematics. The desired position and orientation of the stage determines control signals of the piezos by equation (1).



a. b.

Figure 3: (a) modified control signals applied to electromagnets and piezos, and (b) horizontal y-displacement and vertical z-displacement.

4 Summary

Control signals, which are applied to the positioning stage, are discussed. We change the sequence and voltage of the control signals. Desired position and orientation of the stage determines the control signal of the piezo. In the experiment, the stage motion in horizontal y-direction and parasitic vertical z-direction is measured. The parasitic displacement is reduced by considering the inverse kinematics of the stage.

Acknowledgements:

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References:

[1] A. Torii et al., A six-degree-of-freedom micro parallel kinematic stage for multi-axis positioning, 12th International conference of the euspen, Stockholm, Sweden, vol. 1, pp. 543-546, 2012