Design and Control of a Compact Air Bearing Stage with Planar Motor

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Abstract

This paper introduces a compact-sized air bearing stage with X-Y planar motion driven by electromagnetic motors which has a moving range of 20 mm x 20 mm with a total size of 220 (L) x 220 (W) x 66 (H) mm^3, which is adequate for future use of miniaturized precision machine tools or instruments. The proposed system has a compact and simple configuration by incorporating air bearing pads and moving magnet motors within the moving table. Four single-phase linear motor stators with iron cores and coils are located under the base plate, and air bearings and cores with permanent magnets are attached under the moving table. By combining the actuations of motors simultaneously, X or Y linear motions can be generated, and angular motion is also possible to control. A 3-DOF grid encoder with 10 nm resolution was used for compactness and cost effectiveness.

1 Introduction

The linear motion stage system is essential for building precision machines. These systems should attain the desired positioning accuracy, straight-line movement, and stiffness appropriate for the applications. The selection of bearings, drives, sensors, and controllers is the usual first step in designing a linear motion system. Most machines need three axes of linear motion, and at least two axes should be integrated for generating planar motion (X-Y motion). The simplest technique for accomplishing this is stacking two stages perpendicularly. However, if two or more stages are stacked, the total stiffness will be half that of a single stage, and this configuration also significantly reduces the movement stiffness. In addition, the inertial loads for the upper and lower motors are not the same, resulting in different control bandwidths for the two directions; these effects are more noticeable in compact machine systems. To remedy these issues, we designed a new type of planar XY stage, shown in Figure. 1.

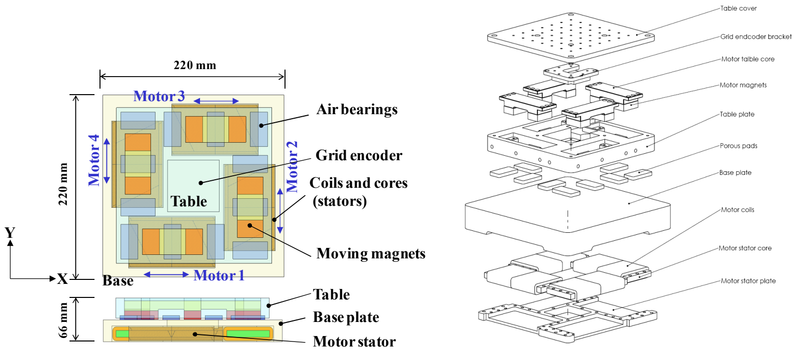

Figure 1: Proposed compact 3-DOF planar stage

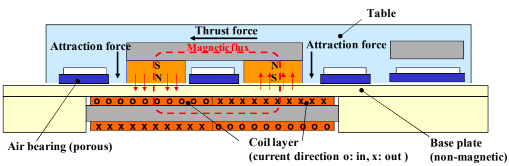

Figure 2: Schematic diagram of linear motor with preload and thrust force

2 Design of a compact planar motor stage

2.1 Motor and preload design.

Figure 2 shows the schematic diagram of the single phase linear motor used in this system. The linear motor has table and base irons and two permanent magnets are attached under the table back iron. The coil layers are on the base back iron. The magnetic fluxes between two cores of the permanent magnets generate attraction forces acting as a preload force for the air bearings. By the currents in the coils thrust forces can be generated proportional to the current. There are four linear motors to generate 3-DOF forces and preloads for the air bearings. The thrust force and attraction force were calculated simply with a magnetic circuit model. For the NdFeB magnets with a size of 20 x 30 x 10 mm^3, flux density of the air gap, attraction force, and thrust forces were calculated. The thickness of the plate between the motor magnets and iron core with coils was determined as 7 mm considering structural deformation. Table 1 shows the designed parameters of the planar stage.

Table 1 Data of fabricated prototypes of the planar stage.

Size (W x L x H)	Table	180 x 180 x 31 mm^3
	Base	220 x 220 x 35 mm^3
Moving range		20 mm x 20 mm
Air bearing clearance (0.5 MPa)		12 µm
Vertical bearing stiffness		> 20 N/µm
Moving weight		3.2 kg
Encoder resolution (Grid)		10 nm
Thrust force	Peak (4A)	40 N
	Cont. (2A)	20 N

2.2 Control system.

To control X, Y and θ movements, a grid encoder was implemented considering compactness and cost effectiveness. This grid encoder has three positional outputs, two X distance signals and Y, so the rotational angle can be calculated by differentiating X_1 and X_2 outputs. As four motors were used three degrees of freedom, s conventional one to one motion control structure cannot be adopted. So, a multi channel motion controller with programmable logic was used. The currents of the coils were amplified with four current amplifiers. Figure 3 shows the block diagram of the control system. The 3-DOF control logic with PID controllers was implemented with Mechaware software for eZMP controller (Danaher Motion Co.). And through this method, three DOF of motions can be corntrolled independently.

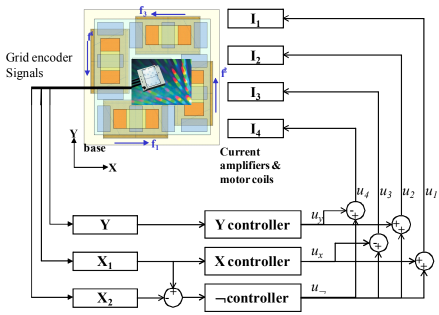

Figure 3: The block diagram of 3-DOF control system

3 Experimental resutls

The prototype was fabricated as shown in Figure 4. The base plate was fabricated by sintering and grinding alumina ceramic (Al_2O_3) which has very low magnetic permeability, high electric resistivity and high structural stiffness. The electric lines were connected to the motor stators under the table base, and pressurized air was supplied to the table for the air bearings. Referring to Figure 5 (which shows the results for all three axes), for 100 encoder counts, X, Y and theta moved 1 μm and 10.3 arcsec, and were clearly separated without cross-talk. The positioning performances were mainly affected by the sensors used, since they were all supported by air bearings.

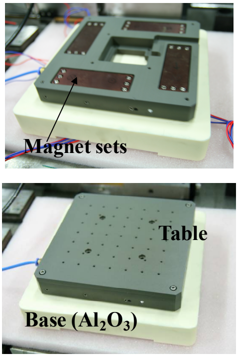

Figure 4: The prototype of planar stage

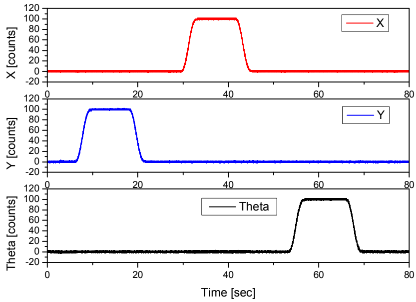

Figure 5: Three DOF movements for 100 counts

4 Conclusions

For compact and precise planar movement, we proposed a new type of surface motor stage with air bearings and four electromagnetic motors which also preload the air bearings. The designed stage was only 220 x 220 mm^2 of foot print area for 20 x 20 mm^2 range of movement. By implementing a grid encoder and a programmable motion controller, we could control three motions separately. The developed system is expected to be applied for ultra precision micro-machines successfully in the future.

References:

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