Development of compact high precision two degree of freedom XY piezoelectric stepping positioner

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In this article, a linear piezoelectric stepping positioner developed by Kang et al. [Rev. Sci. Instrum. 78, 075112 (2007)] is extended to have a two degree of freedom XY linear motion and it is experimentally evaluated. A resolution less than 10 nm, a speed of over 0.5 mm/s, push forces of 17.9 and 19.5, and stiffnesses of 6.54 and 5.90 N/μm are attained while maintaining a compact size of 96×96×39 mm3 and the required power consumption of 102.74 W. © 2008 American Institute of Physics. [DOI: 10.1063/1.2841807]

This article presents a novel two degree of freedom (2-DOF) XY linear piezoelectric stepping positioner extended from the one degree of freedom (1-DOF) positioner of Kang et al.1 It has a simple operation principle, taking the concept of clamping from the inchworm2 and the concept of using a shear piezostack from the walker.3 To obtain 2-DOF XY motion, some modifications are required. First, the shear PZT of the feed mechanism (FM) should be extended to 2-DOF to perpetuate the XY motion. Two orthogonally stacked shear PZTs are used, as shown in Fig. 1(a). At this time, because the length of each shear PZT becomes half of that of the 1-DOF positioner, the speed also falls off to the half of the speed of the 1-DOF positioner. Second, the monolithic-type four clamp mechanisms (CMs) are used to make the drive module symmetric about both the X and Y axes and to reduce the effect of assembly error. The CMs that the FM is attached on are shown in Fig. 1(b). Each CM has the almost same structure as that of the 1-DOF positioner1 and the friction pads attached at the top of the moving part of each CM do the role of holding on the output moving body shown in Fig. 1(d) so that the motion of the FM is not transferred to the output moving body during the clamping period of the operation cycle. Third, as in the CMs, the preload mechanisms (PMs) are also modified to have the symmetric and monolithic structure. Figure 1(c) shows the total drive module turned upside down in comparison with Fig. 1(b) to display the structure of the PM effectively. The outer part is the PMs and the CMs are assembled into the inside of the PMs and the preload adjust screws push up the CMs into the output moving body to obtain the actuating friction force. Finally, 2-DOF XY cross-roller guide is used for guiding the XY motion of the output moving body. As shown in Fig. 1(d), the drive module is assembled below the guide module.

Because the design procedure and equations are similar to the 1-DOF piezoelectric stepping positioner, only the results are presented. P-142.05 (Physik Instrumente GmbH &

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FIG. 1. (Color online) The proposed 2-DOF piezoelectric stepping positioner: (a) top view, feed mechanism; (b) top view, subassembly composed of the feed mechanism and clamp mechanism; (c) bottom view, drive module; (d) top view, fabricated 2-DOF positioner.
Co. KG) is used as the feed PZT and AE0505D16 (NEC TOKIN Corp.) is used as the clamp PZT. The clamp flexure is designed to have a stiffness of 3.23 N/μm, a resonant frequency of 12.02 kHz, a maximum displacement of 16.3 μm, and a maximum stress of 128 MPa. The flexure is made of Al 7075-T6. The preload flexure is designed to have a preload direction stiffness of 3.71 N/μm, a resonant frequency of 917 Hz, and a maximum stress of 183 MPa at a deformation of 50 μm. To adjust the preload, three serially connected disk springs having an outer diameter of 8 mm, an inner diameter of 4.2 mm, and a thickness of 0.4 mm are used. Its maximum force is 193 N and the maximum preload of 400 N can be obtained.

According to the design results, the 2-DOF XY piezoelectric linear stepping positioner is fabricated, as shown in Fig. 1(d). The overall size of the developed 2-DOF positioner is 96 × 96 × 39 mm, and the required power consumption is 102.74 W. The frictional surfaces between the two modules are composed of tool steel to improve the resistance of wear, and they are ground such that the roughness is below 1 μm. As amplifiers of piezoelectric actuators, SVR 350-3 bip (Piezo Mechanik Corp.) for the feed piezoelectric actuators and ENV 400 (Piezojena Corp.) for the clamp piezoelectric actuators are used.

First of all, the fine motion test of the developed positioner is performed. For this, the feed piezoelectric actuator is controlled without applying voltage to the clamp piezoelectric actuators. The proportional-integral control law is used, and 10 nm step control results are shown in Fig. 2. Position is measured by capacitance sensors (Lion Precision, Probe C5-D), and the test algorithm is implemented via Digital Signal Processor (DSP) controller (dSPACE, dSPACE Inc.).

Next, a large motion test based on the piezoelectric stepping movement is performed. Position is measured by a laser Doppler vibrometer (LDV) (Polytec. OFV 501, OFV 3001). As described in Ref. 1, the feed piezoelectric actuators are driven by a 460 Vp.p. sine wave and the clamp piezoelectric actuators are driven by a 140 Vp.p. square wave. The frequency of both signals is set to 150 Hz. Figure 3 shows the forward and backward displacement profiles in the X axis of the positioner with no external load and the results of the Y axis are similar to them. A speed of approximately over
0.5 mm/s is attainable. Figure 4 shows the load-speed characteristics of the positioner under the same drive condition as the above no-load test. Spring force is exerted as the external load and it is measured by the load cell, i.e., a CSBA-10LS (CASKOREA Co. Ltd.), just like the 1-DOF positioner. The drooping load-speed characteristics are also observed in the developed 2-DOF positioners. The maximum loads that the positioner can drive, at which the velocity is decreased to 0.1 mm/s, are measured to be 17.9 and 19.5 N for the X axis and Y axis, respectively.

Finally, the stiffness test of the positioner is performed, as shown in Fig. 5. The deformation by the external spring load is measured by the LDV and the load is measured by the load cell. The slope implies the stiffness of the positioner and the values for the X axis and the Y axis are calculated to be 6.54 and 5.90 N/μm, respectively.