Development of a Planar Resonant Piezostepper

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Abstract

This paper reports on the design, fabrication and assembly of a planar resonant piezostepper positioning system. The positioning system is a key component for the cost-effective fabrication of all kinds of high-precision products. Regardless the machining process, high accuracy, high motion resolution and high stiffness are required. Depending on the size of the product, a long travel can be necessary. To achieve this goal, a stepper comprising 6 piezo-driven modules (legs) was developed that combines high resolution and high stiffness with long travel. The major disadvantage of this positioning system was its positioning speed, which was limited to a few mm/s. To overcome this disadvantage, a new type of piezoelectric drive module has been developed that combines high resolution with high positioning speed, thanks to its resonant operation. By replacing the former piezoelectric stepping modules with the new resonant modules, the stage will be able to move with much higher speeds.

1 Introduction

Drive systems are commonly used throughout the industrial world, but in general they only address one single degree of freedom. If a multiple degree of freedom stage is desired, several stages have to be "stacked" on top of each other, resulting in a series chain of compliances. Multi-degree-of-freedom piezosteppers maintain the stiffness of the actuators by parallel integration of multiple degrees of freedom. This work therefore studies the possibilities of piezosteppers as a basis for rigid and fast positioning. The Leuven piezomotor, a novel drive module [1] that combines very accurate positioning with a fast positioning mode and a virtually unlimited stroke, has been used to replace the stepping modules of a formerly developed slow piezostepper positioning system [2]. This permits the system to move at speeds up to 200 mm/s instead of only 2 mm/s for the old system.

2 Layout of the positioning system

The planar piezostepper stage is a rigid frame holding 3 or 6 piezomotor units which move over a base surface. This base surface is fixed to the world. On top of the stage, the workpiece and the measuring system are fixed. The measuring system assesses the position of the stage with respect to a metrological reference frame. The piezomotor unit consists of a body clamped in the frame and a spherical contact element. The spherical contact element is actuated in two translation degrees of freedom (X and Y labelled) by two or four piezo-actuators inside the unit. The planar piezostepper moves the stage along six degrees of freedom: three for planar movements and another three for motion error compensation. The positioning stage is controlled via a measurement system composed of an encoder and a grid plate. This system can send position feedback with a resolution of 0.05 µm and a range of 105 x 89 mm, which is practically the only factor limiting the motion range of the positioning stage.

2.1 The piezomotor unit

The piezomotor unit is the core of the piezostepper. Figure 1 (a) shows a drawing of the drive module, called the Leuven piezomotor.

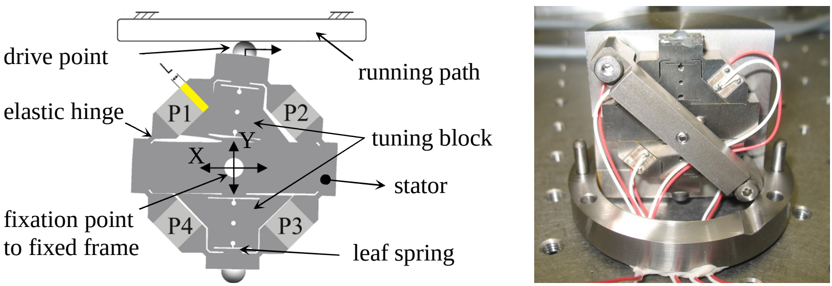


Figure 1: Drawing of the drive module (a) and the fabricated module (b) with its adapter components

It consists of a metal stator structure which is pre-stressed against a slider at the drive point. Four piezoceramic actuators (P1-P4) are mounted inside the stator via flexible elastic hinges. The stator is mounted to a fixed frame at the central point of symmetry.

2.2 Planar resonant piezostepper configuration

2.2.1 Configuration for stepping and resonant mode

In this configuration, 6 drive modules are integrated into the piezostepper (Figure 2a), uniformly distributed over the same circle. Three of them are oriented along the longitudinal direction, and the other three along the transversal direction. Their combined operation allows the stage to run with six degrees of freedom.

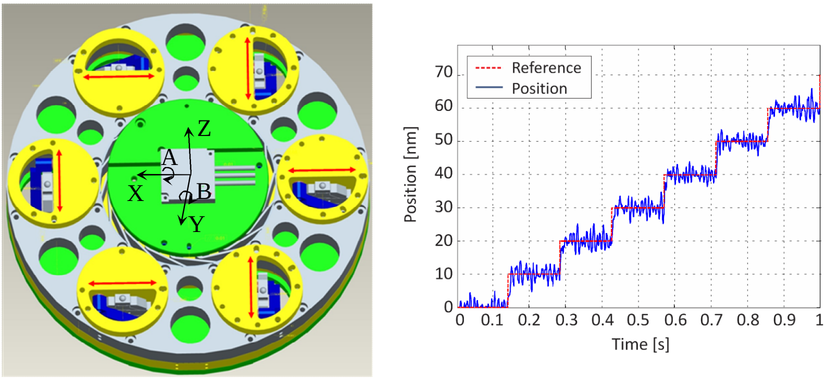
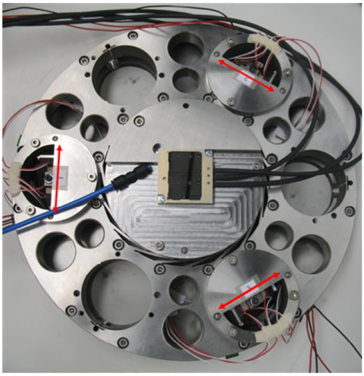


Figure 2: (a) Configuration for the stepping and resonant mode. (b) Driving unit performance.

The stepping mode inherits the advantages of a piezoelectric actuator: high positioning resolution and a high stiffness. Figure 1 illustrates the working principle of the stepping cycle. When a positive voltage is applied to P1 and a negative voltage with the same magnitude is applied to P2, the drive point and hence stepping unit moves to the right. Some of the units drive the stage while others move into their start position; if one group of units is at the end of their stroke, the other group takes over and a new cycle starts. Figure 2(a) shows the motor performance when tracking a staircase function with a step of 10 nm. It features smooth motion and sub-nanometre resolution. This configuration allows movement in any direction (in-plane) by the composed motion of all drive units. For applications requiring a large stroke and high velocity, the resonant operation mode can be used.

2.2.2 Configuration for resonant and stick-slip mode

In this configuration, 3 drive modules are integrated into the piezostepper on a circle at 120° interval, with their drive direction tangent to this circle. Figure 3 (a) shows the integration of the drive units into the stage while Figure 3(b) shows the force-speed characteristic of the drive unit. Next to resonant mode operation, this configuration also allows to work in a stick-slip mode for high positioning resolution. The experimental measurements reveal a maximum speed of the driving unit of 200 mm/s with a positioning resolution of 40 nm.



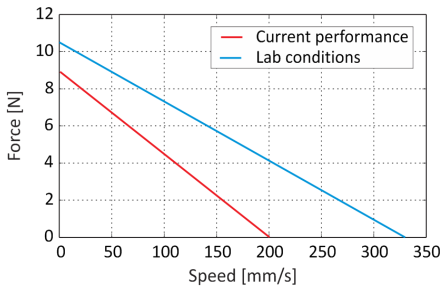


Figure 3: (a) Configuration for the resonant and pulse mode. (b) Driving unit performance under resonant mode.

3 Conclusion

A planar resonant piezostepper has been developed which holds either 3 or 6 Leuven piezomotors. The piezostepper solution is a viable alternative for applications where rigid positioning, high resolution and high speed are required. Future work will focus on the control architecture, active bearing functionality and out-of-plane motion error compensation.

References:

[1] W. Van De Vijver, D. Reynaerts, H. Van Brussel, *Development of a highly-accurate and fast piezoelectric linear positioning system,* PhD, 2008

[2] H. Van Brussel, D. Reynaerts, P. Vanherck, M. Versteyhe, S. Devos, *A Nanometre precision, Ultra-stiff Piezostepper Stage for ELID-grinding,* CIRP Annals, Vol. 52/1/2003, pp 317-322.