XVIII IMEKO WORLD CONGRESS
Metrology for a Sustainable Development
September, 17 – 22, 2006, Rio de Janeiro, Brazil

EXPERIMENTAL AND NUMERICAL CHARACTERIZATION OF *XY* PIEZOELECTRIC NANOPOSITIONERS

Gilder Nader [a], *Ronny Calixto Carbonari* [1b] *and Emílio Carlos Nelli Silva* [2b]

[a] Instituto de Pesquisas Tecnológicas do Estado de São Paulo, São Paulo, Brazil, gnader@ipt.br
[b] Department of Mechatronics and Mechanical Systems Engineering Escola Politécnica da Universidade de São Paulo, São Paulo, Brazil
[1b] ronny@usp.br [2b] ecnsilva@usp.br

Abstract: XY nanopositioners consist of two piezoceramic actuating a compliant mechanism. Prototypes were manufactured in aluminum using a wire EDM process, and bonded to PZT5A. Finite element simulations were carried out using the commercial ANSYS software application. Experimental analyses were conducted using laser interferometry to measure displacement, while considering a quasi-static excitation.

Keywords: nanopositioners, MEMS, laser Interferometry.

1. INTRODUCTION

XY nanopositioners have a wide range of applications in precision mechanics [1] such as cell manipulation, microsurgery tools, nanotechnology equipment, electronic microscopy instruments, lens positioner for laser interferometer, and mainly microelectromechanical systems (MEMS) [2,3]. Therefore, it consists in a technology in development whose applications are growing in the world. However, the development of these nanopositioners requires the design of micromechanisms that perform complex movements without presence of joints and pins, due to manufacturing constraints of micro-tools scale. This can be achieved by applying the compliant mechanism technology. In a compliant mechanism the movement is given by the structure flexibility rather than the presence of pins and joints [3], which makes possible to transmit nanometers and micrometers displacements

In this work, some prototypes of these novel multi-actuated piezoelectric flextensional devices were manufactured and analyzed to characterize their behavior. These prototypes were designed by using topology optimization [4], and they consist essentially of PZT5A piezoceramics bonded with epoxy to an Aluminum flexible structure manufactured by using a wire EDM (Electrical Discharge Machining) machine (figure 1a). These flexible structures have complex forms that can provide movements with minimum coupling among actuated piezoceramics.

Experimental displacement measurements were performed to evaluate the prototype performances in terms of movement coupling and output displacement. Since these devices are used in static or quasi-static mode (that is, lower than first resonance frequency), displacements and amplifications are determined by considering very low excitation frequencies. To measure piezoelectric mechanisms displacements, a low cost laser interferometer is applied. These results were compared with the finite element simulation results obtained by using ANSYS™ [5] software, a commercial FEM package (figure 1b).

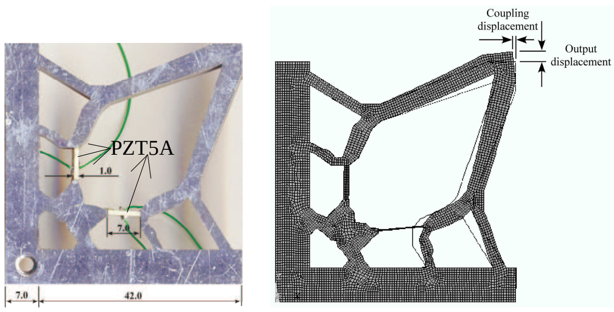

Fig. 1. a) *XY* nanopositioner (unit *mm*) and b) Deformed of *XY* nanopositioner.

2. FINITE ELEMENT ANALYSIS

Since the devices have a prismatic shape, 2D FEM models were built. Once the depth of actuators is small in relation to their other dimensions the plane stress assumption is adopted. These FEM models is shown in figure 1b. The Young's modulus and Poisson's ratio of Aluminum are equal to 70 GPa and 0.33, respectively.

3. LASER INTERFEROMETRY

Multi-actuator piezoelectric device displacements are measured by using laser interferometry since it allows us to perform dynamic measurements (static and harmonic) in the kHz range which is the order of the first resonance frequency of these piezomechanisms. The interferometric system setup used is a low cost and very precise to perform these measurements allowing us to measure displacement amplitudes in nanometric range. Among several interferometric techniques applied to measure displacements of piezoelectric transducers [5, 6] laser interferometry has more precision and resolution [7]. The principle of laser interferometry used in this work is to measure displacements from a phase shift of an optical wave due to the movement of a sample [6]. The displacement of the sample is obtained in terms of the known laser wavelength (λ). A phase difference of π corresponds to a displacement of $\lambda/4$. This is a sensitive and efficient method to measure small displacements and deformations and it was used to obtain dynamic displacement measurements. A Michelson-type quadrature interferometer, as shown in figure 2, is applied to measure quasi-static displacement response of piezoactuators in one single point. It uses a He-Ne laser source (λ = 632.8 nm). A half-wave plate ($\lambda/2$) is used to control the intensity ratio to reference mirror (R) and sample analyzed (S), which are reflected and transmitted by a polarizing beam splitter (PBS). The convergent lens L1 is applied to focus the laser beam in the reference mirror and sample surface. Between the two beam splitters (BS1 and BS2) there is no interference, because the reflected light from R and S are orthogonal polarized. After the polarizer A1 (at 45°), the reference and sample lights are in the same polarization, then, there is interference. The light reflected by BS2 passes through a quarter-wave plate ($\lambda/4$) at 45°, which is the $\pi/2$ phase shifter, in this application. After the quarter-wave plate the light passes through a polarizer A2 at (at -45°). The interference patterns acquired by amplified and balanced photo-diodes (PDA1 and PDA2) are shifted by $\pi/2$. A convergent lens L2 is applied to expand the laser beam and enlarge the interference pattern on PDA1 and PDA2. The main advantage of the quadrature interferometer is that it is a non-stabilized interferometer less subjected to the environmental vibrations [6].

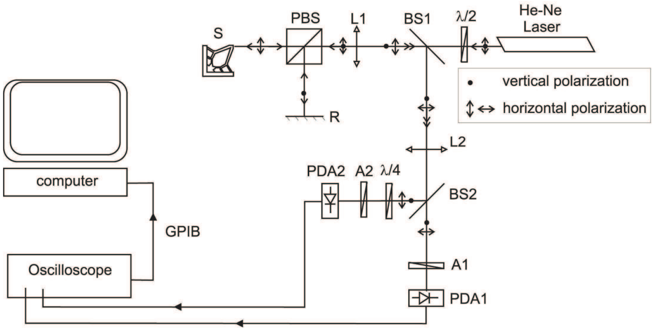

Fig. 2. Experimental setup of Michelson-type quadrature interferometer.

4. EXPERIMENTAL AND SIMULATIONS RESULTS

Since the laser interferometer can only measure displacements and the actuator operate in a static mode, displacement measurements are done considering quasi-static excitation, by applying a harmonic sinusoidal excitation (continuous mode) at 60 Hz. The objective is to compare experimental and numerical displacement in X and Y direction, by considering generated displacement and coupled displacement. Results are shown normalized at 100 V/mm. In table 1 are illustrated experimental and numerical displacements results for Nanopositioner XY05b, which is designed for low coupled displacement.

This nanopositioner shows an good agreement between experimental and numerical results for generated and coupled displacement, as shown in Table 1, and also for coupling rate. Some differences between experimental and numerical results can be dependent of nanopositioner holder. In a future work, new analysis will be conducted to verify the influence of mechanical holder in the microactuators behavior. Thus, a qualitative analysis for coupling rate for each nanopositioner shows that these devices have the expected behavior as designed by topology optimization.

Table 1. Results normalized for 100 V/mm.

	Output displacement	**Coupled displacement**	**Coupling rate**
Numerical	51.9 nm	8.5 nm	16.4%
Experimental	40 nm	8 nm	20.0%

5. CONCLUSIONS

Novel designs of multi-actuator flextensional piezoelectric devices were successfully manufactured and characterized by using laser interferometer. A low cost Michelson interferometer was used to perform the experimental verification of amplification rate of prototypes. Quasi-static measurements were conducted to characterize piezomechanism behavior. From the results obtained experimental and simulated results matched well showing that FEM models were able to represent the multi-actuator behavior, and that multi-actuator piezoelectric devices designed by topology optimization (which is based on FEM) performed as predicted in the initial design specifications.

REFERENCES

[1] H. Ishihara, F. Arai, and T. Fukuda, “Micro mechatronics and micro actuators," IEEE/ASME Transactions on Mechatronics Vol 1, No 1, pp. 68-79, 1996.

[2] D. Reynaerts, J. Peirs, and H. Brussel, “A mechatronic approach to microsystem design," IEEE/ASME Transactions on Mechatronics Vol 3, No 1, pp. 24-33, 1998.

[3] L. Howell, “Compliant Mechanisms,” John Wiley & Sons, Inc., New York, USA, 2001.

[4] R. C. Carbonari, E. Silva, and S. Nishiwaki, “Topology optimization applied to the design of multi-actuated piezoelectric micro-tools," in Proceedings of Modeling, Signal Processing and Control {11th SPIE (AnnualInternational Symposium on Smart Structures and Materials) Vol. 5383, pp. 277-288, 2004.

[5] J. Monchalin, “Optical detection of ultrasound," IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control Vol. 33, No 5, pp. 485-499, 1986.

[6] C. B. Scruby and L. E. Drain, “Laser Ultrasonics, Techniques and Applications,” Adam Hilger, EUA, 1990.

[7] D. Royer and E. Dieulesaint, “Optical detection of sub-angstrom transient mechanical displacements," in IEEE Ultrasonic Symposium Proceeding, pp. 527-530, 1986.