INVESTIGATION OF POWERFULL AND HIGH PRECISION PIEZOELECTRIC ACTUATOR FOR TWO-DIMENSIONAL POSITIONING

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Summary The investigation of novel design high precision piezoelectric actuator for the object positioning in two-dimensional space is presented. Piezoelectric actuator has main advantages of large driving force, high dynamic resolution and short response time. Optimization analysis of piezoelectric actuator and numerical investigation using finite element method were done. Results of numerical and experimental research were compared.

INTRODUCTION

A lot of devices based on the different techniques are used for the object positioning in two-dimensional space. Piezoelectric actuators are advanced in this field of machinery [1]. Usually piezoelectric actuator moves slider or turns rotor in one dimensional space while multidimensional movement of the positioning object is achieving by using complex mechanical systems. Most of the high precision piezoelectric actuators have small-scale driving force, so its not applicable for weighty objects positioning. Novel design for high precision piezoelectric actuator is investigated in this paper. This actuator achieves driving force till 10N and has positioning accuracy till 10 nm. Due to the special design of the actuator object positioning in two-dimensional space is achieved.

CONCEPT OF TWO-DIMENSIONAL POSITIONING

Principle of elliptic moving trajectory of the actuator contact core is based on exciting the ends of the beam *ab* (Fig. 1) by two harmonic loads that have the same frequency, but different phases by π/2. With the given loads flexural

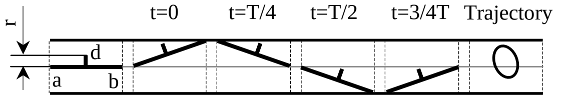

Fig.1 The position of the beams through every quarter the oscillations period

oscillations of the beam are excited. So moving trajectory of contact point *d* (Fig.1) can be written as follows:

$$\zeta(t,x)=r\left(\frac{\partial\xi(x)}{\partial x}+\frac{\xi(l)}{l}\right)sin(\omega t+\varphi) \qquad \delta(t,x)=\xi(x,t)+r\left(1-\left(\frac{\partial\xi(x)}{\partial x}+\frac{\xi(l)}{l}\right)sin(\omega t+\varphi)\right) \tag{1}$$

where $\zeta(t,x)$ and $\delta(t,x)$ are displacements of the contact core in horizontal and vertical directions accordingly, $\xi(x,t)$ is flexural oscillations of the beam, ω is the oscillation frequency, r is the length of contact core, l is length of the beam, t is the time and φ is the phase. Second modal shape of the beam must be exited in order to achieve driving force maximum of the piezoelectric motor. Special actuator for body positioning in the plane was developed concatenating two oscillating beams perpendicularly. Depending on excitation control actuator can position object in two perpendicular directions and achieve linear, curvilinear and rotational motion of the positioning object.

FEM MODELLING OF THE ACTUATOR

Basic dynamic equation of the piezostack-based actuator can be written as follows [2]:

$$\left.\begin{array}{r}[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}+[T_1]\{\phi_1\}+[T_2]\{\phi_2\}=\{F\}\\ [T_1]^T\{u\}-[S_{11}]\{\phi_1\}-[S_{12}]\{\phi_2\}=\{Q_1\}\\ [T_2]^T\{u\}-[S_{12}]^T\{\phi_1\}-[S_{22}]\{\phi_2\}=\{0\}\end{array}\right\} \tag{2}$$

where [M], [K], [T], [S], [C] are accordingly matrices of mass, stiffness, electroelasticity, capacity, damping, $\{u\}, \{\phi\}, \{F\}, \{Q\}$ are accordingly vectors of nodes displacements, potentials, external mechanical forces and charges coupled on the electrodes. Referring to Eq. 2, vector of external mechanical forces can be calculated as follows:

$$\{F\}=\left([T_2][S_{22}]^{-1}[T_2]^T-[T_1]\right)\{U\}sin\,\omega_k t \tag{3}$$

where $\{U\}$ is the vector of voltage amplitude. Modal analysis of the piezoelectric actuator was done in order to find out proper natural frequency and modal shape (Fig.2a) for the contact point elliptic trajectory formation. A full harmonic response analysis was performed to give an adequate response curve of the contact point (Fig.2b) and to calculate parameters of elliptic trajectory (Fig. 2c) at the resonance frequency.

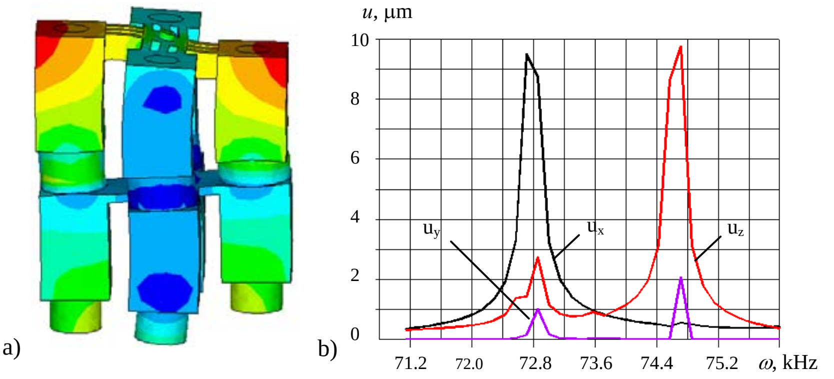

Fig.2 Results of actuator numerical investigation: a) modal shape at 73.59 kHz, b) amplitude versus frequency display, c) trajectory of contact points at 73.3 kHz

OPTIMIZATION OF THE ACTUATOR

Trajectory of the contact point strongly depends on geometrical parameters of the actuator, so optimization of actuator must be performed. Actuator (Fig. 2a) is analysed as frame of vertical and horizontal beams. Length of the beams is chosen as optimization parameters. Difference between first natural frequency longitudinal oscillation of the vertical beams and second natural frequency of flexural oscillation of the horizontal beams is chosen as optimization criteria. It allows achieving the best trajectory of the contact point. Optimization problem can be written as follows.

$$\begin{cases} \omega_{l1} - \omega_{f2} \Rightarrow max \\ l_h < l_{h\_cr} \\ l_v < l_{v\_cr} \end{cases} \tag{4}$$

where ω_{l1} is first natural frequency of longitudinal oscillation of the vertical beam, ω_{f2} is second natural frequency of flexural oscillation of the horizontal beams, l is the length of the beams.

EXPERIMENTAL RESEARCH

Experimental research was carried out in order to find distribution of the oscillations amplitudes on the surfaces of actuator, trajectories of the contact core movement and driving force characteristics (Fig.3). Experimental investigation also must sustain theoretical prerequisites of the object positioning in the plane using this type of actuator.

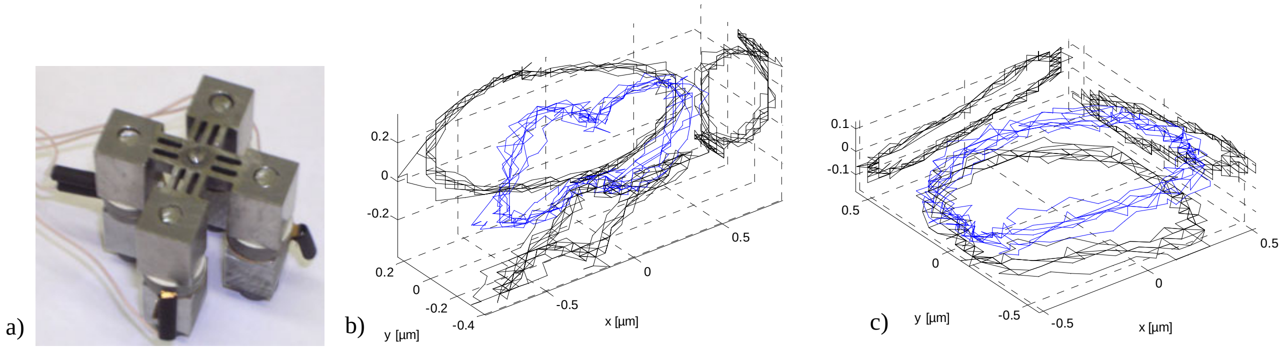

Fig. 3 Experimental model of the piezoelectric actuator (a), three dimensional trajectory of the actuator contact point when exciting two opposite shoulders (b) and all four shoulders of the actuator (c)

CONCLUSIONS

High precision piezoelectric actuator of the novel design was developed for the object positioning in the plane. Results of numerical and experimental investigation confirmed the possibility to use this type of piezoelectric actuator for two-dimensional positioning.

References

[1] Kenji Uchino.: Piezoelectric Actuators and Ultrasonic Motors. Kluwer Academic Publishers, Boston/Dordrech /London, 1997.
[2] Bansevicius R., Barauskas R., Kulvietis G., Ragulskis K.: Vibromotors for Precision Microrobots.Hemisphere Publishing Corp., USA, 1988.