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Investigation of oscillations of piezoelectric actuators with multi-directional polarization

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ABSTRACT

Oscillations of two beam type piezoelectric actuators with non-homogeneous polarization are investigated. 3DOF oscillations of the contact point are excited applying harmonic signal on the electrodes of the actuators. Elliptical motion of the contact point is generated in the three perpendicular planes independently. Investigated actuators can move or rotate slider in three different directions. Superposition of flexural resonant oscillations in two perpendicular directions and longitudinal resonant oscillation of the beam is employed to obtain elliptical motion of the contact point. Performed investigation demonstrates that the piezoelectric actuators with non-homogeneous polarization provide an effective solution for generation a multi-DOF motion of the contact point. Both proposed actuators have specific topology of the electrodes that allows to control contact point trajectory by means of particular excitation regimes. The paper presents results of numerical modeling as well as experimental study obtained in the course of testing of the fabricated prototypes of the actuators.

1. Introduction

Development of the piezoelectric actuators for nano-positioning, manipulating systems, control equipment and robotics is becoming increasingly important [1–3]. Piezoelectric actuators have advanced features such as high resolution, short response time, compact size, and good controllability [4]. Piezoelectric actuators can operate in resonant or non-resonant modes therefore many design principles of piezoelectric actuators are proposed and used [3–5]. Most of the piezoelectric actuators operate as single degree of freedom (DOF) mechatronic system and has limited applicability [3,5,6]. Only few multi-degree-of-freedom actuators are developed that capable to generate vibrations of contact point in two or three directions [7–12]. Usually, mechanical systems composing several actuators are used for two-dimensional (2D) or three-dimensional (3D) positioning of the object that is each DOF uses separate actuator [3,4]. However, such design principle reduces accuracy of the whole system, because it is impossible to manufacture piezoelectric actuators with identical mechanical characteristics. Therefore, a complex control system must be used to ensure independent control of each actuator. Multi-DOF actuators allows overcoming this problem but development of such actuators is complicated.

Piezoelectric actuators with non-homogeneous polarization is one of the design principle of multi-DOF actuators [13]. Direction of polarization vector and orientation of the electrode plane defines vibration mode and the plane of mechanical vibrations of the actuator. Therefore, direction of contact point vibration can be controlled by changing direction of polar-

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ization vector. Also it must be mentioned that characteristics of contact point motion strongly depends on electric signal and excitation regimes of the electrodes. Multi-directional polarization of piezoelectric actuators allows increasing functional characteristic and applicability of the actuators.

Two beam type multi-DOF piezoelectric actuators with non-homogeneous polarization along the length of piezoelectric actuator is proposed i.e. beam actuator with quadratic cross-section and cylindrical actuator. Actuator with quadratic cross-section had two-directional polarization while cylinder type actuator had radial polarization. Numerical modeling of piezoelectric actuator was carried out to evaluate operating principle by analyzing trajectories of contact point under different excitation schemes. Prototype actuators have been made and experimental study was performed. Finally, the results from numerical simulation and experimental study were analyzed and discussed.

2. Design of piezoelectric actuator

2.1. The main principle of the actuators design

Contact point of 3 DOF actuator must produce elliptical motions in three perpendicular planes independently in order to move or rotate slider in three different directions. Superposition of flexural resonant oscillations in two perpendicular directions and longitudinal resonant oscillation of the beam is employed. Both flexural and longitudinal resonant frequencies must coincide to achieve appropriate elliptical motion of the contact point. Flexural oscillations of the beam type actuator can be obtained in two perpendicular directions at the same resonant frequency when shape of the structure is symmetric and bending stiffness in the both directions is the same.

Multi-mode oscillations consisting of the 1st longitudinal and 3rd flexural oscillation modes of the beam were chosen as operating mode of the both actuators (see Fig. 1). These modes define particular dimensions of the beam and can be calculated by equalizing equations of resonant frequencies of longitudinal and flexural modes [7]. In our case, the ratio of height and length of the beam type actuator is equal to 0.09.

Based on these requirements, two bulk piezoceramic beams with quadratic and circle cross-section were chosen to build non-homogeneous polarized actuators. Actuator with quadratic cross-section was polarized in two perpendicular directions on the first and second half of the actuator respectively. Both vectors of polarization are perpendicular to the longitudinal axis of the beam and d31 effect is used for generating mechanical vibrations of the beam. Quadratic cross-section and two-directional polarization of the beam allows to excite vibrations of the actuator in two perpendicular planes independently therefore the first multi-DOF actuator was designed as the beam with quadratic cross-section. Contact point of the actuator was defined in the middle of the top surface of the actuator. The second piezoelectric actuator consists of a core metal rod placed inside piezoceramic hollow cylinder coated by thin silver electrode (Fig. 5). The outer diameter of the core

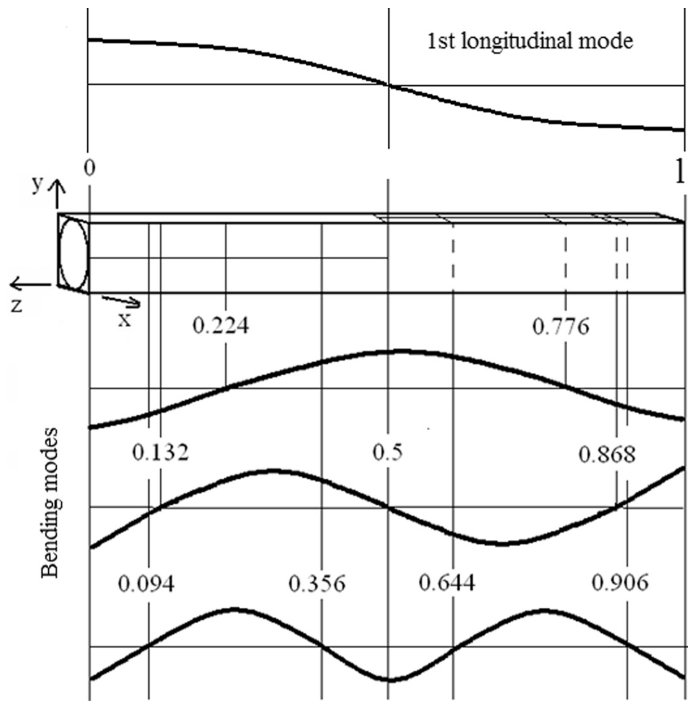

Fig. 1. Principle of modes superposition of longitudinal and flexural oscillations of a beam type actuator.