Various Types of Piezomechanics Systems: Their Regimen and Experimental Analysis

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Abstract. The layered piezoactuators used in mechanisms requiring high precizion displacements have indicated that accuracy depends on design and technological factors. One of essential requirements for compound piezoactuators is their capability of transferring unipolar or bipolar force. In the first version, the piezoactuators acting in one direction is made of separate piezoelements and adapted binding materials. They operate under positive deformation (elongation due to neutral position) when the applied voltage is positive to polarity. The layered piezoactuators returns to its initial position under negative deformation (contraction) when the polarity voltage is applied opposite. The piezoactuators deformation in this direction only due to small forces of binding materials. When the piezoceramic is deformed by an external electric field, the input electrical energy is larger than the output mechanical energy. The ineffective electrical energy is stored as electrostatic energy in the piezostack and reverts to the power supply in the final process of an operating cycle. The efficiency is determined only by the loss such as hysteresis in the strain curve. The electromechanical feedback affects the correction of the hysteresis. It is evident that by applying the electromechanical feedback the hysteresis can be corrected up to 0.2% from the maximum displacement.

1. Introduction

One of the essential requirements for layered piezoactuators is their capability to transfer unipolar or bipolar forces. In the first case, a piezostack acting in one direction is made of separate piezoelements and special binding materials. They operate in a mode of their positive deformation (elongation due to neutral position) when the applied voltage is positive inspect to polarization. A piezostac returns to its initial position under negative deformation (contraction) when voltage of opposite sign is applied to binding materials. Mechanisms of this type are frequently used in adaptive optics and various mechanical systems. The second case ensures the possibility of displacements in opposite directions from the neutral position – bipolar force. That happens when a piezostac elongates from the initial position under the positive deformation while the deformation to the opposite direction occurs as a result of the elastic strain. Layered piezoactuator with a piezostack is superior over those with a single-layer because summing up. Deformations of each element, the displacement of a layered piezoactuator can be increased. Their mechanical properties are also significantly augmented. Therefore, dynamic characteristics of each individual element of a layered piezoactuator have to be determined separately. Layered piezoactuator piezoelements with similar characteristics have to be selected for assembling of layered piezoactuators. The input electrical energy is larger than the output mechanical energy, when piezoceramics are deformed by external electric field. The ineffective electrical energy is stored as electrostatic energy in the piezoconverter and reverts to the power supply in the final stage of an operating cycle, because displacement of a layred piezoactuator can be increased by summing up deformations of each elements. For selection of constructional and technological parameters the algorithm of dynamic characterisitcs has been set up constructional and technological parameters. Parameters of internal deformations have been also evaluated.

Mechanical and electrical laws pertaining in layer piezostack are analysed separately and their interelation is written by a mathematical expression [1]:

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$$\left.\begin{aligned} m_1\ddot{x}_1 + F_y\left(x_1 - x_2, \dot{x}_1 - \dot{x}_2\right) + H_1\left(\dot{x}_1 - \dot{x}_2\right) + c_1\left(x_1 - x_2\right) + H_0\dot{x}_1 + c_0 x_1 = F_B\left(t\right) \\ m_2\ddot{x}_2 - F_y\left(x_1 - x_2, \dot{x}_1 - \dot{x}_2\right) + H_1\left(\dot{x}_2 - \dot{x}_1\right) + c_1\left(x_2 - x_1\right) = -F_B\left(t\right) - P_H \end{aligned}\right\} \tag{1}$$

where m_1 and m_2 – two masses; F – the strain; c – parameter of intensity; H – damping; x_1 and x_2 – coordinates; $F_B\left(t\right) = A\sin\omega t$ – harmonic force of stimulation.

$$F_B\left(t\right) = \begin{cases} A, kT \le t \le kT + T/2 \\ -A, kT + T/2 \le t \le \left(k+1\right)T \end{cases} \tag{2}$$

where A – amplitude; T – period, k – number of period.

Solutions of system:

$$\begin{aligned} x_1 = a_0 + a_1\cos\omega t + a_2\sin\omega t \\ x_2 = b_0 + b_1\cos\omega t + b_2\sin\omega t \end{aligned} \tag{3}$$

Theoretical calculations of the first harmonics of vibrations, in case of harmonic excitation of a layered piezoactuator, call for a conclusion that the initial compression and the mechanical load of piezoelements increase the amplitude of vibrations.

According to the calculations the layered piezoactuator of constituent elements tied together by binding material (composite piezoconverters) compose a system with a great static strength. For this reason, such systems are used in mechanisms operating under heavy loads and requiring very precise displacements. The layered piezoactuator used in mechanisms requiring high displacements have indicated that accuracy depends on design and technological factors [2-4]. Layered piezoactuator can be bimorph, axial and combined stacks. One of the essential requirements for compound vibration drives is their capability to transfer unipolar or bipolar forces. In the first version, the layered piezoactuator acting in one direction is made of separate piezoelements and adapted binding materials. They operate under positive deformation (elongation due to neutral position) when the applied voltage is positive with respect to polarization. The layered piezoactuator returns to its initial position under negative deformation (contraction) when opposite sign voltage is applied to binding materials. Mechanisms of this type are frequently used in adaptive optics. The second version ensures the possibility of displacements to opposite directions from the neutral position – bipolar force. This happens when the layered piezoactuator elongates from the initial position due to the positive deformation while the deformation to the opposite direction occurs as a result of the elastic strain. Layered piezoactuator are superior over those with a single-layer owing to the fact that by summing up the deformation of each element, the displacement of a layered piezoactuator can be increased. Their mechanical properties are also significantly augmented. Therefore, dynamic characteristics of each individual element of layered piezoactuator have to be determined separately. When assembling the piezoconverter piezoelements with similar characteristics have to be selected. When piezoceramics are deformed by external electric field, the input electrical energy is larger than the output mechanical energy. The ineffective electrical energy is stored as electrostatic energy in the layered piezoactuator and reverts to the power supply in the final process of an operating cycle.

By choosing the optimal number of piezoelements, by maintaining the production conditions which do not limit the displacement value but limit the piezostack deflection from the vertical axis it is possible to achieve the desired displacement value with less power and lab our expenditure (figure 1). The conclusion can be made that stability of piezoengines, the wide range of their control, transmission precision are of never diminishing interest to the scientists investigating piezomaterials.

In order to determine more precisely the initial stress values in a piezoactuator and to choose the optimal version in the rotary converter design, a few piezoelements are inserted into the sensor. They significantly improve the operation parameters of the piezoactuator increasing in accuracy and releability. The structure and measurement characteristics of this actuator, namely, its capacity variation on the measured force value are illustrated in figure 2. This measuring method has been chosen because measuring and selecting the tension force value should not damage the structure. The sensor of such a structure precisely reads back the measurement results and its normal operation depends on that of a rotary converter [5, 6]. The sensor error is determined by a measurment capacity error which is 0.25% of the maximum value and a calibrating error. Layered piezoactuator based on axial piezopackets may be adapted for application in calibration of elements of optical systems. This enables displacements in micron and submicron range simultaneously ensuring high loading capacity.

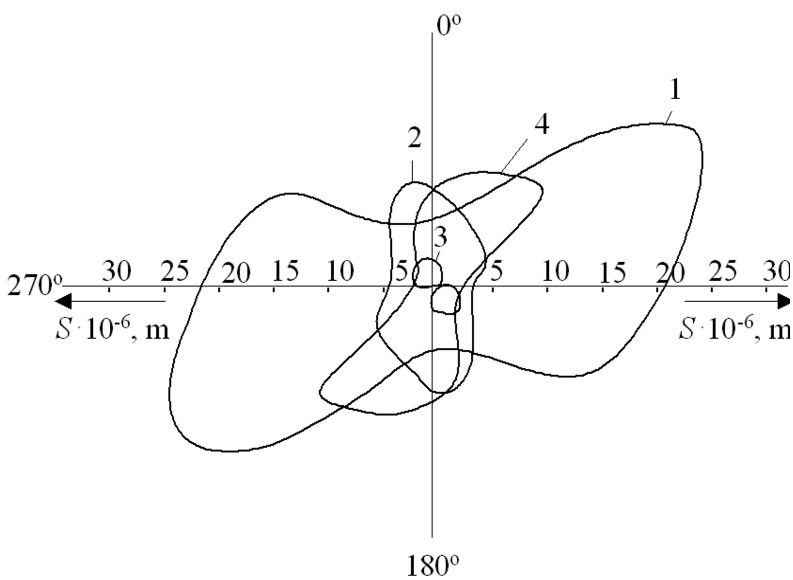


Figure 1. Deflection of layer piezoactuator from sensor.

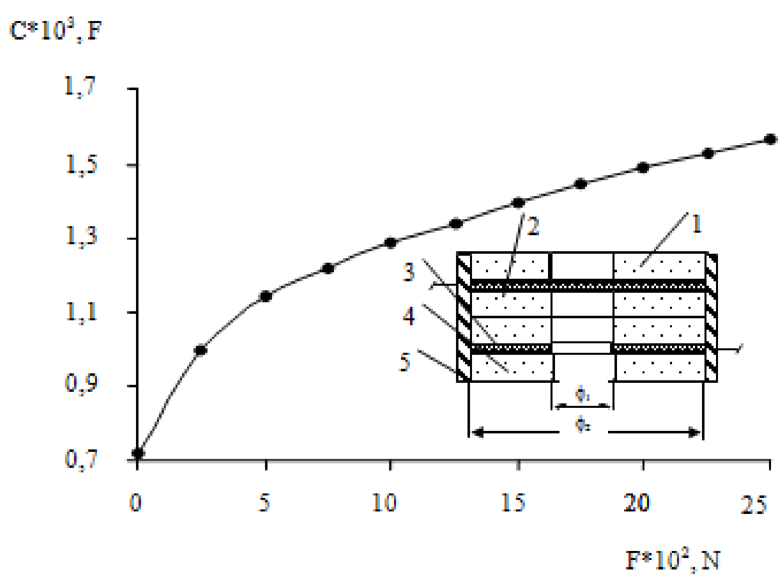
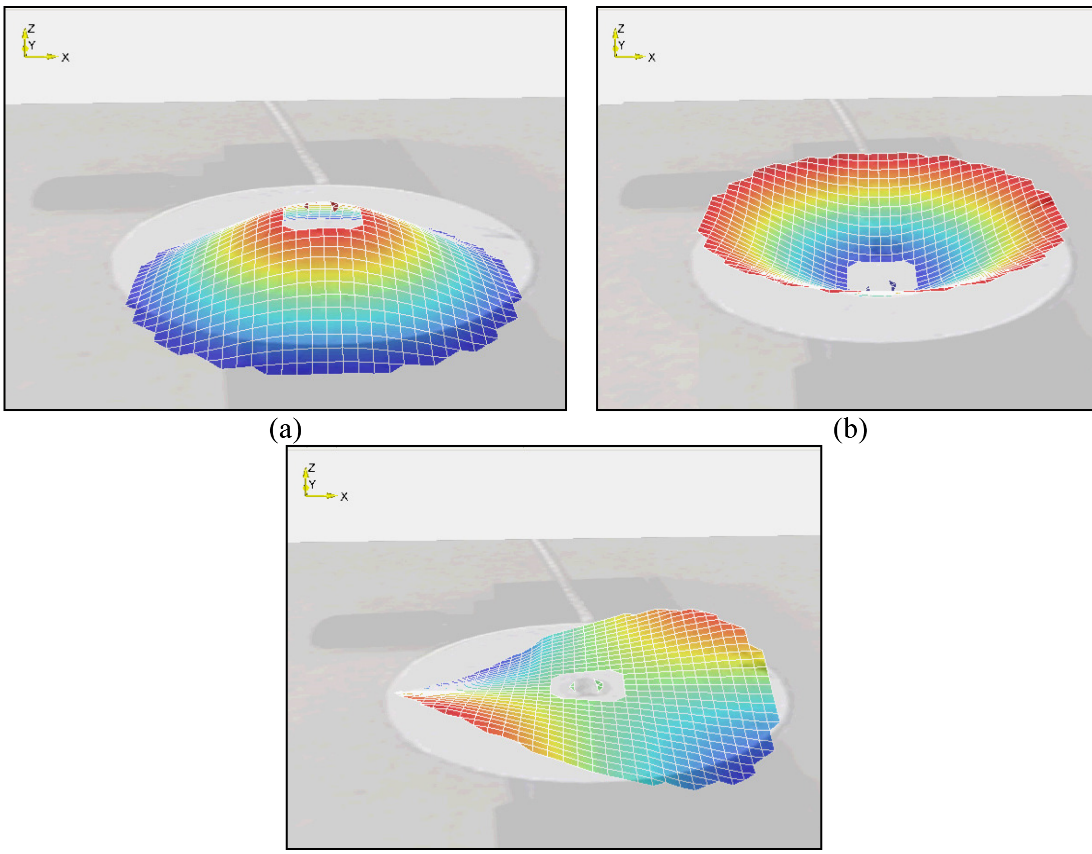


Figure 2. Scheme of piezelectric capacity and its capacity force characteristics (4 piezoelements with removed):
1 – electrodes; 2, 3 – active elements with one electrode;
4 – piezoelements; 5 – binding material.

The initial measurements of mechanical vibrations in a layered piezoactuator were performed with a purpose to define the behaviour of the output part of the combined stack excited by the electric vibrations of certain frequency. Measurements were performed using a highly sensitive laser interferometer produced by a company "Polytec". The device includes an integrative generator for the excitation of vibrations which is capable to excite a layered piezoactuator (figure 3). This method of excitation allows simplifying the measurement of extremely low motions, since simultaneous synchronisation of the generator and the measurer of vibrations allows eliminating positional changes between the measurer and the object of measurement.



(a) (b) (c)

Figure 3. Images of the sequence of measurement when resonance frequency:
a) 21.2 kHz, b) 21.2 kHz, c) 16.2 kHz.

The performance of several measurements of the amplitude movements on the output part of layered piezoactuator on the same moments of a fluctuation period, and the subsequent calculation of the arithmetic mean of measures taken allows more accurate evaluation of a real value of the amplitude. There more measurements, performed on a certain moment of a discrete period, are used for the calculation of the arithmetic mean, there more exact evaluation is obtained.

2. Conclusions

Investigation of piezomaterials and dynamic experiments of their structural parts have indicated that loading forces and increase in the initial tension decrease harmonic components of fluctuations. Natural frequencies of the piezostack significantly decrease with an increase in the number of piezoelements. Experimental investigation of compound piezostacks make it possible to determine optimal initial tension force, the dependence of displacement of a loose piezostack on some constructional and technological parameters.

The experimental investigation of layered piezoactuators with combined stack have revethe possibilities to optimize the design and materials for obtaining maximum displacements. On the results of investigation modern designs of piezoactuators with combined piezostacks for high precision displacements can be developed. The overall dimensions of the piezoactuator (depending on quantity of piezoelements) is strictly defined since the device has to meet stringent requirements for achieving maximal motion amplitude. Therefore optimization of piezoelements and layered piezoactuator design has been performed together with dimensional analysis of spring-type pressing device, which key criteria is to estimate achieve maximal displacement amplitude of piezoactuator output part.

Holographic interferometry method and Polytec Scanning vibrometer PSV-400 used in the experimental work has strengthened the expressions of differential equations and used for describing conclusions of the investigation

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