Analysis of combined piezoelectric actuators

L. Patašienė, G. Baurienė

Mechanical Engineering

Kaunas University of Technology

Introduction

Technical possibilities of combined piezodrives used in piezoactuators are analysed and reported in many works [1-3]. These piezoactuators are used in gyroscopes, telescopes, various optical systems and are mainly applied for military purposes. Under severe environmental conditions these structures are to be thoroughly investigated. Mechanical and electrical laws pertaining in combined drives are analysed and their interelation is given by a mathematical expression:

$$\begin{aligned} \bar{\sigma} &= \left[c^E\right]\bar{\varepsilon} - [e]\bar{E}\,, \\ \bar{D} &= [e]^T\bar{\varepsilon} + \left[\text{э}^S\right]\bar{E}\,. \end{aligned} \tag{1}$$

Here σ is the mechanical stress; D is the vector of electric displacement; [c^E] is the stiffness tensor; [e] is the tensor of a piezoelectric constant; [э^S] is the tensor of a dielectric constant.

The stiffness matrix $[K_0]$ is expressed as:

$$[K_0] = \int_{V^e} [B]^T \left[C^E\right][B]dV\,, \tag{2}$$

where the matrix $[B]$ is determined by deformations and displacements $\bar{\varepsilon} = [B]\bar{\sigma}^e$, and the matrix $[B]^T$ is the transformation matrix $[B]$:

$$\int_{V^e} d[B_L]^T \{\sigma\}dV = [K_\sigma]d\{\delta\}, \tag{3}$$

where $[B_L]^T$ is the transformation matrix $[B_L]$ estimating nonlinearity of deformations, $[K\sigma]$ is the matrix which estimates piezoelectric properties described by Eq. (1). The coefficient of proportionality λ indicates the extent of the load increase in order to obtain the critical strength [δ]. The critical load – $P_{kp} = P\ \lambda$.

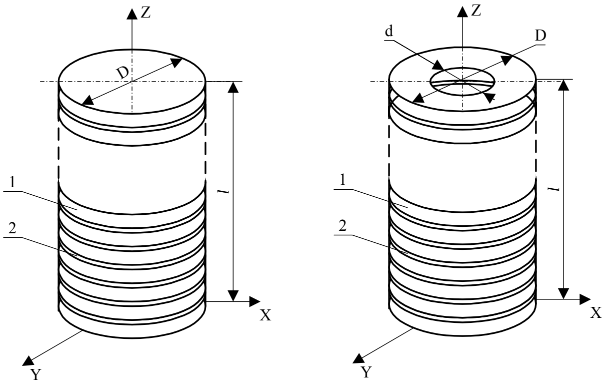
The values of critical loads are obtained for the following piezodrives (Fig.1):

a) with disk elements P_{kp} = 280244.48 N,

b) with ring elements P_{kp} = 269455.07 N.

Analysis

According to the calculations the piezodrives of constituent elements tied together by a binding material into piezostacks is a system having a great static strength (Fig.1). For this reason, these systems are used in mechanisms operating under heavy loads and requiring very precise displacements. The piezodrives used in mechanisms requiring high precision displacements have indicated that accuracy depends on design and technological factors.



a b

Fig. 1. **Piezodrives of constituent elements piezostack: (a) – disk elements, (b) – ring elements :1- piezoceramic element, 2 – binding material**

The piezodrive has been investigated under a dynamic regime and without it. It should be noted that dependence of the current flowing through the piezostack, (Fig. 2), and depending on the frequency of piezoelements deformations makes it possible to choose the right power regimes, to design excitation and control systems and also to select the optimal mechanical and electric parameters.

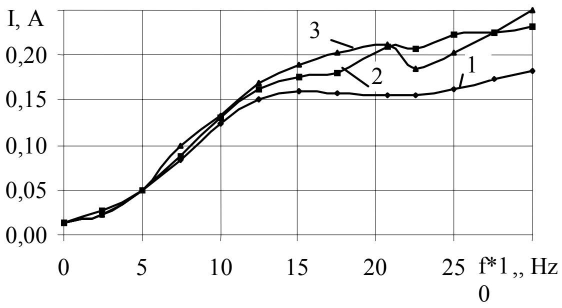


Fig.2. **Dependence of the current flowing through the piezostack on the frequency of deformations under forces:1- 700N, 2- 1200N, 3- 1500N**

In order to obtain the maximum displacements in piezodrives the material and diameter for the pin (Fig.3), must be properly chosen as they both provide the initial stress. The choice of the initial stress enables to determine exactly the operation range for the piezopacket to meet the functional requirements for precise displacement mechanisms.

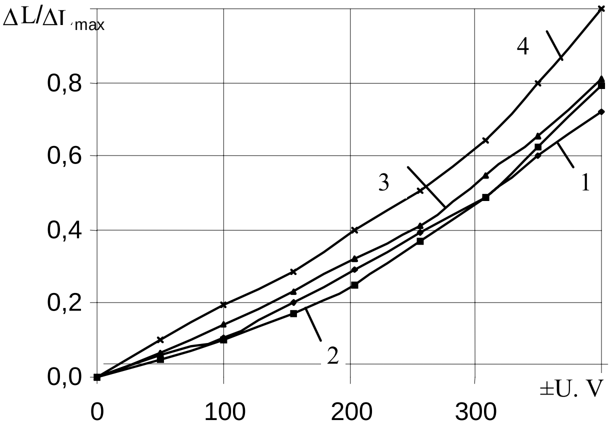


Fig.3. **Dependence of displacement values on supply voltage with different materials of a pin:1- steel 30G, 2-steel 65G, 3-titanium alloy OT4, 4- beryllium bronze**

Fig. 4 illustrates the dependence of piezostack displacement on the value of the initial stress for various diameters and materials of the pin. The work with piezoelements has revealed a great effect of the internal loses in piezoceramics expressed by a hysteresis loop of an ellipse shape. Experimental invesigation enables us to draw the conclusion that the electromechanical feedback affects the correction of the hysteresis loop, as shown in Fig. 5. It is evident that by applying the electromechanical feedback the hysteresis loop can be corrected up to 0.2% from the maximum displacement.

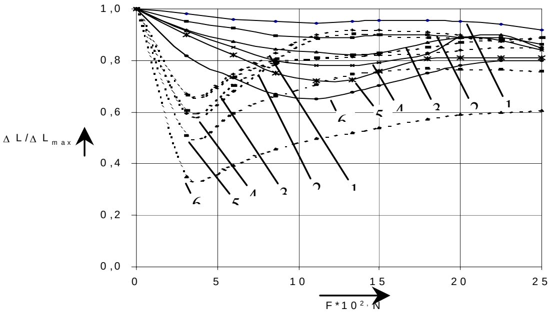


Fig.4. **Dependence of the piezostack displacements on the initial stress for various pin sizes: 1– 2mm, 2– 2.5mm, 3– 3mm, 4– 4mm, 5 – 5mm, _____ beryllium bronze, _ _ _ _ titanium alloy**

In order to determine more precisely the initial stress values in a piezostack and to choose the optimal version in the piezodrive design, a few piezoelements are inserted into the sensor.They significantly improve the operation parameters of the actuator increasing in accuracy and releability. The structure and measurement rezults of this actuator, namely, its capacity variation on the measured force value are illustrated in Fig. 6.

The experimental investigation has made it possible to choose the designs for various optimal systems. The combined vibrodrives can be used for working separately or in pairs, or they can work all together if the mirror is made of segments (e.g. 6 or more). Fig. 7 presents the design of a piezodrive used for control of a telescope secondary mirror. It consists of two piezostacks 7 installed in the frame 4 with the initial stress developed by the pin 3.

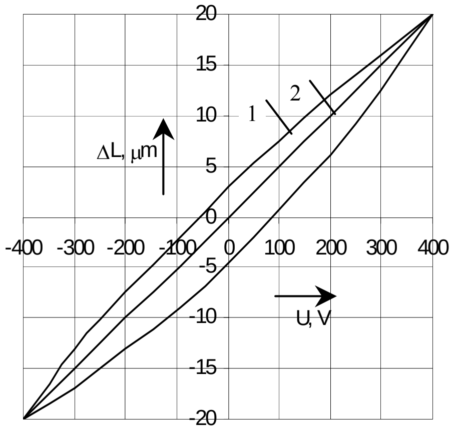


Fig.5. **Hysteresis loops corrected in a piezostack versus the feedback value:1- without a feedback,2- with a feedback**

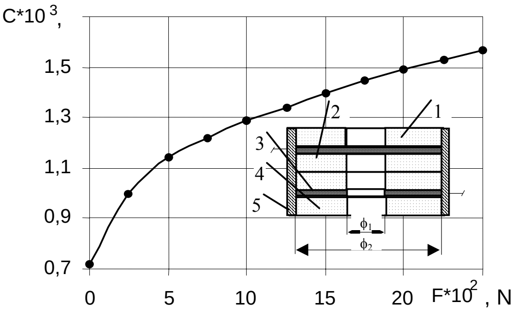


Fig. 6. **Scheme of piezelectric capacity sensor and its capacity - force charackteristics:1-4 piezoelements with removed electrodes; 2-3 active elements with one electrode; 5 - binding material**

The pin piercing both piezopackets is fixed at caps 6 to which flexible hinges 5 are screwed by nuts 2. The mirror 8 and equalizer 1 are located at equal distances in opposite directions.

When one piezostack is contracting, simultaneously, the other is extending and forcing the mirror and equalizer to move in opposite phases thus eliminating negative deformations, which may be transferred to the telescope frame and impair some optical parts.

The combined piezodrive design is shown in Fig. 8. It ensures three degrees of freedom to a slid-over object. The piezodrive consists of two rigidly connected parts. At the bottom there is the piezostack 4 with the initial stress developed by the pin 5, a cap consisting of the intermediate disk 3 and the plate 7 and also the base 2 elastically connected to the brick 1. The upper part has two pairs of

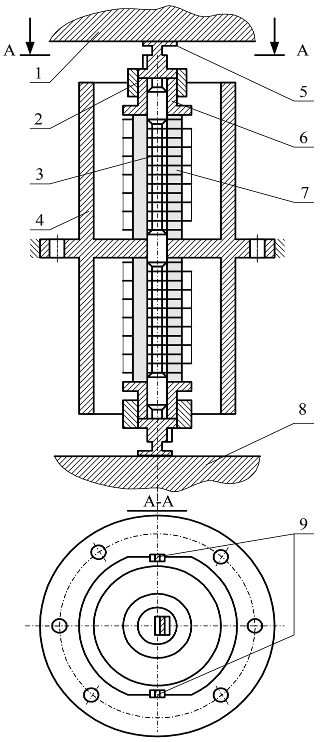


Fig.7. **Design of a piezodrive controlling the secondary telescope mirror**

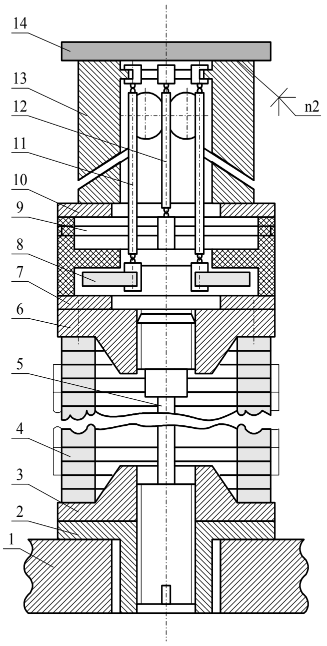


Fig.8. **Combined piezodrive for the controlled mirror actuator in three DOF**

bimorphs 8 and 9 installed in the frame, it is elastically connected to the frame by the plate 10. By means of rods 11 and 12 the bimorphs are connected to the hinges and the motion is transmitted to the mirror through the hinge 13. The bottom part of the piezodrive ensures the object displacement up to 0.1 mm, while the upper part exerts the angular displacement to two coordinates whose amplitude reaches 0.2 in the frequency range (0 -1000) Hz.

Conclusions

The bifurcation problem of a piezodrive has been solved by evaluating piezostacks physical properties of piezoelements and binding material. It has made it possible to prove that piezopackets have a lot of static possibilities. The original solution of the acuator enabled the choice of optimal initial stresses in piezostacks.

The experimental investigation of piezodrives with combined packets have revealed the possibilities to optimize the design and materials for optaining maximum displacements. The automatic control has been determined to affect the correction of the hysteresis loop thus allowing to reduce a displacement error up to 0.2 %. Exploiting the results of investigation, modern designs of piezodrives with combined piezostacks for high precision displacements can be developed. These mechanisms may be applied in various optical systems under harsh and complicated exploitation conditions.

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L. Patašienė, G. Baurienė

Pavarų su sudėtiniais pjezoelektriniais keitikliais analizė

Reziumė

Išspręstas bifurkacinis pjezopaketo uždavinys, įvertinant fizines pjezoelementų ir tarpinės medžiagos fizines savybes. Įrodyta, kad pjezoelektriniai keitikliai turi dideles statinių galimybių atsargas. Originalios pavarų konstrukcijos leido parinkti optimalias pradines pjezokeitiklių įtampas.

Pavarų su sudėtiniais pjezoelektriniais keitikliais eksperimentiniai tyrimai parodė, kad galima optimizuoti konstrukcijas ir medžiagas, norint gauti maksimalius poslinkius. Automatinio valdymo histerezės kilpos koregavimas turi įtakos poslinkio paklaidai ir leidžia ją sumažinti iki 0,2%.

Sukurtos naujos konstrukcijos yra stabilios ir tinka naudoti optinėse sistemose.

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