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Investigation of technological parameters of piezostacks assembling and their application

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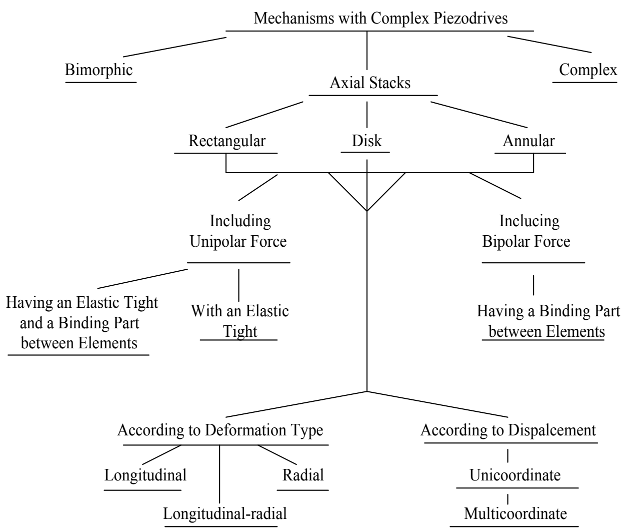
Introduction

Complex piezodrives are frequently used in mechanisms. They can be bimorph, axial and complex-combined stacks:



This work deals with axial piezostacks used in piezotransducers. They make it possible to develop a unipolar or bipolar motion which ensures the displacement dependent on each piezoelement of the compound stack section [1]. Axial stacks (Fig.2) displacing in one direction from the neutral point are made of separate piezoelements and connected by means of binding materials , such as glue or a pin tightening them. These stacks transmit the motion to the mechanism which needs it, positive deformation (swell), while the retreat takes place due to natural negative deformation (shrink). It should be emphasized that the characteristics of a piezoelement subjected to the initial tension differ significantly from those of a piezoelement subjected to other internal forces. Therefore, dynamic characteristics of each individual element of compound piezodrives have to be determined separately. When assembling an axial stack, the piezoelements with similar characteristics have to be selected.

Analysis

Axial stacks have been theoretically investigated by creating a dynamic model. It consists of concentrated masses M and k - interelement packings. For selecting constructional and technological parameters the algorithm of dynamic characterisitcs has been set up. The parameters of internal deformations have been also evaluated.

The common equation of an axial piezostack motion is given by [2]:

$$[M]\{\overline{\overline{X}}\}+[H]\{\overline{X}\}+[C]\{X\}+\{F(X,\overline{X})\}=\{F_b(t)\}+\{P_H\},$$

where $\{X\},\{\overline{X}\},\{\overline{\overline{X}}\}$ are the vectors of displacements, mass and accelerations, respectively; $[M],[N],[C]$ are the matrices of mass, shock-absorption, elasticity, respectively; $\{F(X,\overline{X})\}$ is the vector of nonliner forces; $\{F_b(t)\}$ is the vector of internal deformations due to electric voltage; $\{P_H\}$ is the vector of loading force.

Theoretical investigation of piezostacks and dynamic analysis of their components (Fig.1) have indicated that an increase in the loading force and initial tension decrease the harmonic components of fluctuations. Natural piezostack frequencies sharply decrease with an increase in the number of piezoelements.

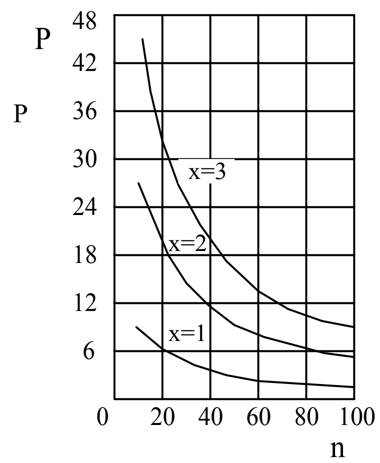


Fig. **1 Dependence of natural frequencies on the number of piezoelements (n), x (1,2,3) different mass, P – tension forces**

The piezoelements of PKR-7M ceramics (ϕ 18x 6xO.8 mm) have been experimentally investigated. The initial tension has been obtained by tightening piezoelements with a sufficiently elastic pin made of beryllium bronze. Fig. 3 presents the dependence of piezoelement displacement on the initial tension force.

Curves 1, 2, 3 are obtained by applying tension forces 20N, 150N, 200N respectively.

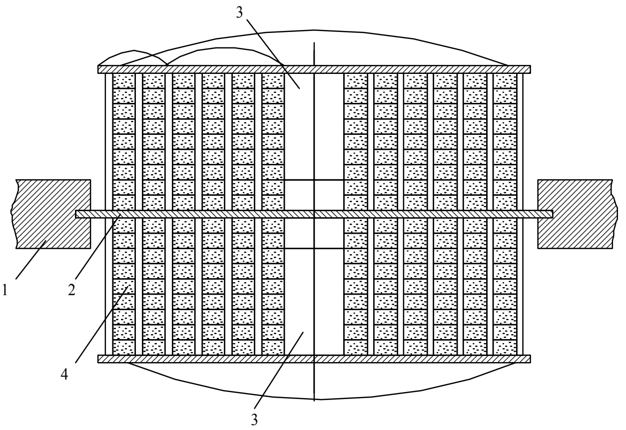


Fig. 2 **Adaptive mirror: 1 – supports, 2 - base, 3 - mirrors, 4 – axial stacks**

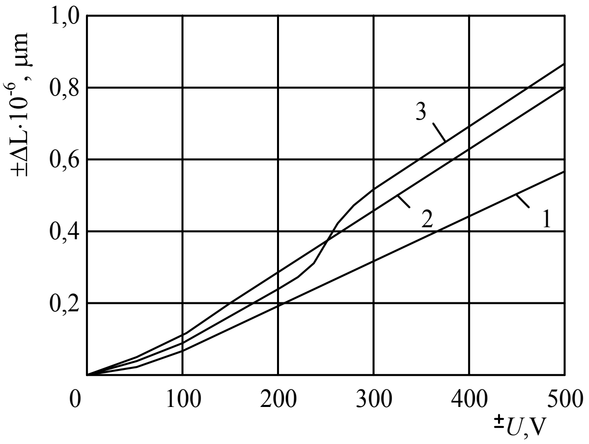


Fig. 3. **Dependence of piezoelement displacement on the voltage under different initial force values: 1- 20N, 2 -150N, 3 - 200N**

Fig.4 presents the amplitude-frequency characteristic under different tension forces: 700N, 1200N, 1500 N.

Application of piezodrives as particular microdrives has indicated that the value of piezostack displacement depends on construction complexity and also on technological factors. For this reason, in the first case the piezostack displacement has been analyzed under zero loading force, while in the other cases - under dynamic regime.

To carry out this analysis a batch of 25 piezostacks has been investigated. There were 65 active elements, 2 passive elements separating the piezostack from the frame and a force converter in each piezostack.

This measuring method has been chosen because measuring and selecting tension force value should not damage the structure. It is of great importance to select identical piezostacks and apply them in a common vibrodrive. Temperature expansion coefficient of the transducer material should be unified with the piezodrive temperature fluctuation because of complicated operation conditions and the fluctuation of environment temperature.

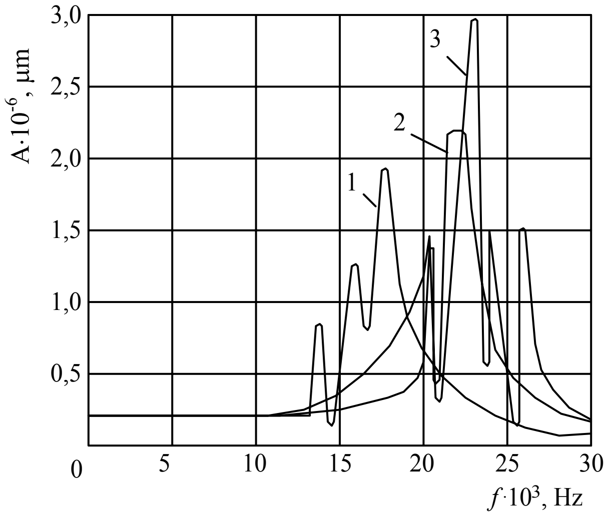


Fig.4 **Amplitude frequency response under different tension forces 1- 700N, 2 -1200N, 3 -1500N**

To fulfil these requirements the converter material is to be analogical to that of a piezodrive, i.e. piezoceramics [3]. The converters of such structure precisely read back the measurement results and their normal operation depends on that of a piezodrive. The converter error is determined by measurement capacity error which is 0.25% of the maximum value and the calibrating error.

Piezodrive glueing technologies have been also examined and serviceability of binding material between piezoelements is reflected by curves in Fig. 5.

Piezostacks have been made of different materials, however, their manufacturing technology was absolutely identical. In Fig. 6 the curves show the piezodrives displacements when using piezoelements of different ceramics. In order to get the greatest displacement in a piezodrive the size of the pin and its material is to be taken into account.

The analyzed criteria have made it possible to choose the piezostacks of an optimal construction having a maximum displacement assembled of PKR-7M with the binding material ЭД-20 and a beryllium bronze pin of 2 mm diameter, (Fig.7). The loading characteristics have been analyzed in piezostacks by changing the supply voltage from +100V to 400V, Fig. 8. The loading-compression force is marked by a dotted line, the loading-tension force – by a solid line. This graph reveals the dependence of a piezostack having the initial tension: increasing the tension force without any initial tension the piezostacks disintegrate, while the value of displacement in a piezostack with the initial tension decreases very slightly. It is the point of great importance in adaptive optics devices where piezostacks can be fastened only at one end, while the free element end is to bend to both sides from the state of equilibrium when loaded up to 500 N.

Experimental investigation of piezostacks have shown that an increase in the number of elements does not result in displacement increase. Therefore, in order to determine

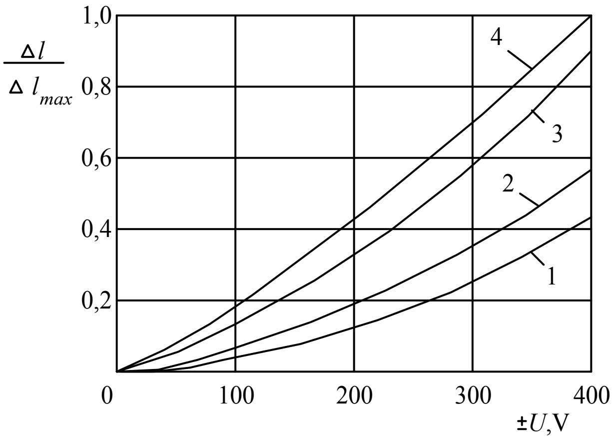


Fig. 5 **Dependence of the piezostack displacement on the supply voltage using different binding materials:1 - glue БФ 6, 2 - glue БФ2, 3 - solder Rose; 4 - epoxy resin ЭД2О**

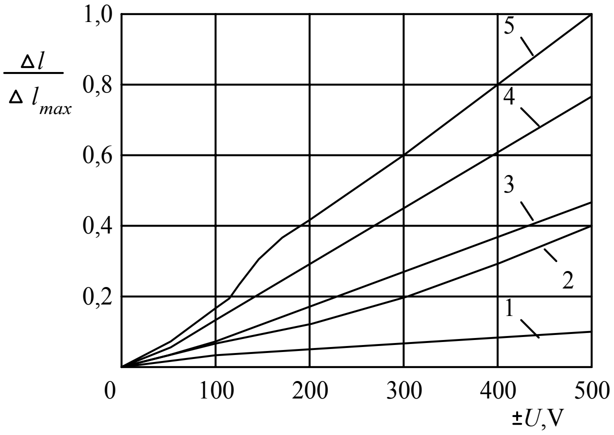


Fig.6 **Dependency of piezostack displacement on the supply voltage using different ceramics:1- ПКП16; 2 - ПКР22; 3 - ЦТС19; 4 - ПКР12; 5 - ПКР7М**

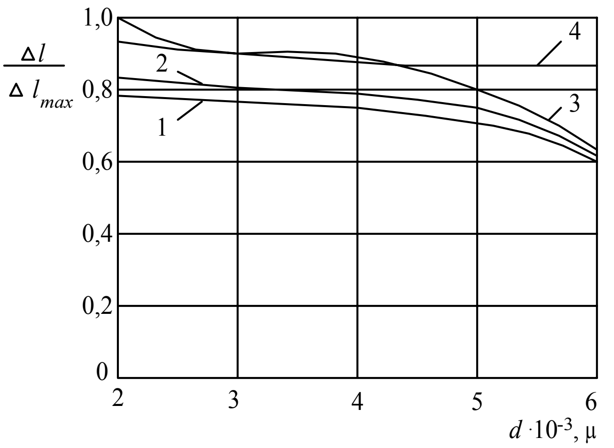


Fig. 7 **Dependence of piezostack displacement on the pin diameter with different pin materials: 1- steel 30; 2- steel 65Г; 3 – titanium alloy ОТ4; 4 – beryllium bronze Б2**

the dependence of the value of displacement amplitude on the quantity of piezoelements in a stack, several stacks have been made with different number of piezoelements, but applying the same manufacturing technology. The tension force value has been maintained the same for all piezostacks (Fig. 9). It is evident that beginning with 60 piezoelements an increase in the number of piezoelements has no substantial effect on the stack displacement amplitude.

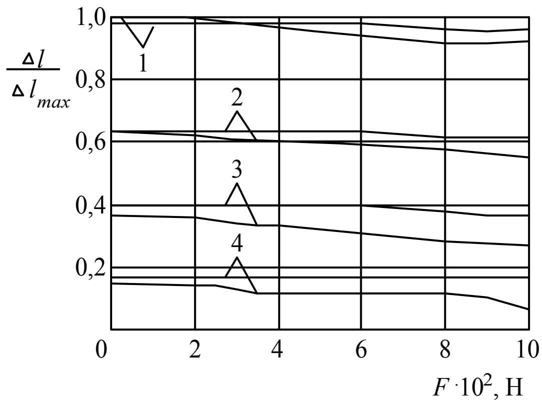


Fig.8. **Dependence of piezostack displacement on the loading force: 1 – U=+300V; 3- U=+200V; 4- U=+100V**

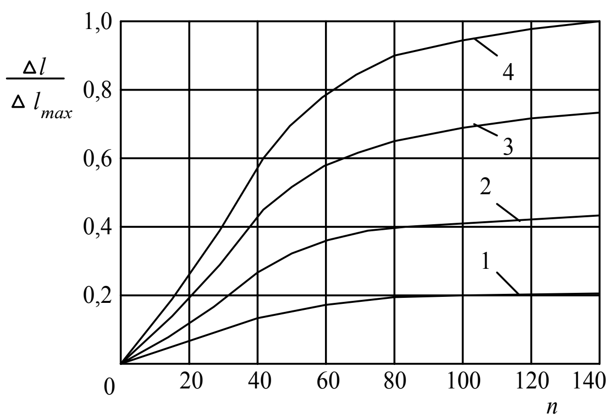


Fig. 9. **Dependence of piezostack displacement on the number of piezoelements:1– U= +100V; 2 – U= +200V; 3 – U= +300V; 4 - U=+400V**

The displacement of a free (not fastened) end of a piezostack on the plane has been analyzed, i.e. the .value of the deflection from the vertical axis has been determined. The experiment has been made under the supply voltage of +500 V. The piezostacks made in absolutely the same way have been tested and their results indicate that the deflection from vertical axis is a purely random value.

It has been assumed that dissimilarity of the planes of separate piezoelements is up to 7.3 (minimum value is 3.9) and that it is the cause of the motion of the free piezostack end on the complex trajectory, as well as the undesirable deformations along the entire length of a stack [4]. Then the conclusion has been made that the main displacement is produced by a bottom part of a piezostack, while the upper part (approximately 1/3 of height) develops deformations of negligible usefulness. In addition to the investigation results (Figs 9 and 10) this fact admonishes that precaution should be taken when choosing the number of piezoelements for obtaining the higher displacement amplitude. The desired displacement value can be achieved with a lower power and labour expenditure if the optimal number of piezoelements is selected and manufacturing conditions are observed which do not restrict the displacement value, but restrict the deflection of piezostack from the vertical axis.

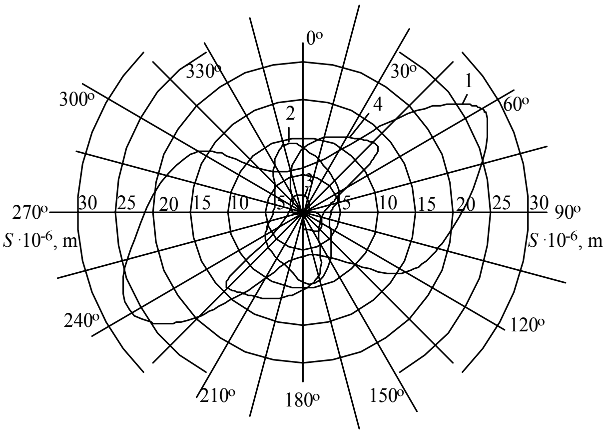


Fig.10. **Deflection of piezostacks from the vertical axis: piezostack 1; piezostack 2; piezostack 3; piezostack 4**

Conclusions

Theoretical investigation of piezostacks 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 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. There exist the possibilities to optimize the construction, materials and technology of the piezostack manufacturing which can result in the maximum displacement value of a piezostack. All experiments have been carried out under mechanical loads. The analysis has indicated how cautiously should the number of piezoelements for a piezostack be selected for obtaining the higher displacement amplitude. 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 labour expenditure.

The distribution of elastic deformations along the entire length of a piezostack has allowed us to develop the recommendation for minimizing the piezoelements.

Dynamic characteristics of compound axial piezostacks have been determined [4]. It has been determinated that they are working in a wide frequency range and successfully reproduce the assigned motion law.

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Pjezopaketų surinkimo technologinių parametrų tyrimai ir jų panaudojimo galimybės

Reziumė

Teoriniai pjezopaketų ir jų sudėtinių dalių dinaminiai tyrimai parodė, kad apkrovimo jėgos ir pirminio įtempimo didinimas mažina svyravimų harmonines dedamąsias. Savasis pjezopaketo dažnumas ryškiai sumažėja padidinus pjezoelementų skaičių. Sudėtinių pjezopaketų eksperimentiniai tyrimai leidžia nustatyti optimalią pradinę įtempimo jėgą, neįtvirtinto pjezopaketo poslinkio priklausomybes nuo daugelio konstrukcinių ir technologinių parametrų. Turime galimybę optimizuoti tokių pjezopaketų konstrukciją, medžiagas ir gamybos technologiją, ir gauti pjezopaketo maksimalų poslinkio dydį.Visi šie tyrimai atlikti esant mechaninėms apkrovoms. Tyrimų duomenys rodo, kad atsargiai reikėtų parinkti pjezopaketų elementų skaičių, norint gauti kuo didesnę poslinkio amplitudę. Norimą poslinkio dydį galima gauti mažesnėmis energinėmis ir darbinėmis sąnaudomis, jei optimaliai bus parinktas pjezoelementų skaičius ir išlaikytos gamybos sąlygos, kurios neriboja poslinkio dydžio, bet riboja pjezopaketo nukrypimą nuo vertikaliosios ašies.Tampriųjų deformacijų pasiskirstymas per visą pjezopaketo ilgį leido pasiūlyti minimizuoti pjezoelementus. Teorinius tyrimus patvirtino eksperimentiniai tyrimai.

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