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Holographic interferometry method for determination of layer piezostack parameters

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Abstract

Complex piezomaterials are frequently used in various mechtronics systems. The piezomaterial used in layer piezostack requiring high precision displacements have indicated that accuracy depends on design and technological factors. The analyzed criteria have made possible to choose the piezomaterial of an optimal mechatronic systems having a maximum displacement. The experimental investigation of precision vibrosystems by means of holographic interferometry enables one to obtain appreciably larger amounts of information about the vibrating surface in comparison with traditional methods. On the basis of the developed methodology of analyzing the experimental data derived from the holographic interferometry and by using the experimental holography stand, we have obtained results making it possible to optimize the design of operation of the mechatronic system or its separate elements.

Keywords: piezomaterial, mechatronics systems, holographic interferometry, layer piezostack.

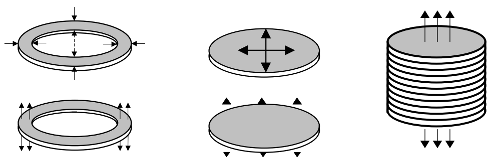
Introduction

Complex piezomaterials are frequently used in various mechanical systems. The piezomaterial used in a layer piezostack requiring high precision displacements have indicated that the accuracy depends on design and technological factors. The ineffective electrical energy is stored as electrostatic energy in the piezoceramic material and reverts to the power supply in the final process of an operating cycle. The analyzed criteria have made possible to choose the piezomaterial of an optimal construction having a maximum displacement. Piezoengines having a layer piezostac are superior over those with a single-layer piezostac owing to the fact that by summing up the deformation of each element the displacement of a layer piezostac can be increased. Their mechanical properties are also significantly improved. Therefore, dynamic characteristics of each individual element of a layer piezostac have to be determined separately. When assembling the layer piezostac, the piezoelements with similar characteristics have to be selected. The experimental investigation of precision vibrosystems by means of holographic interferometry enables one to obtain appreciably larger amounts of information about the vibrating surface in comparison with traditional methods.

Analysis

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

It happens when the piezostack part 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. Piezoengines having a compound piezostack are superior over those with a single-layer piezostack owing to the fact that by summing up the deformation of each element the displacement of a compound piezotransducer can be increased.



a b c

Fig. 1. **View of the constituent piezomaterial of rings elements (a), disk elements (b), layer piezostack (c)**

Their mechanical properties are also significantly improved. Therefore, dynamic characteristics of each individual element of a compound piezostac have to be determined separately. Mechanical and electrical laws pertaining in layer piezostack are analysed separately and their interelation is given by a mathematical expression:

$$\bar{\sigma} = \left[c^E\right]\bar{\varepsilon} - [e]\bar{E}$$
$$\bar{D} = [e]^T\bar{\varepsilon} + \left[\ni^s\right]\bar{E} \qquad (1)$$

where σ - mechanical stress; D – vector of electric displacement; $[c^E]$ – stiffness tensor; $[e]$ – tensor of piezoelectric constant; $[\ni^s]$ – tensor of dielectric constant. The stiffness matrix $[K_0]$ is expressed by:

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

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

$$\int_{V^e} d[B_L]^T \{\sigma\} dV = [K_\sigma] d\{\delta\} \qquad (3)$$

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

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

Upon having analysed the stack made of piezomaterial, the authors have estimated that amplitude frequency response of a piezostack depends on a temperature range. To maintain the same piezostack operational properties the investigation been carried out with the aim to find out the conditions ensuring the stability of a mechanism.

In Fig. 2 the curve 1 represents the frequency response of the layer piezostack under natural climatic conditions. The curves 2 – 7 – the frequency responses at the temperature of –50°C. The experiments were performed in the temperature range of ±50°C. The layer piezostack was examined for 1.5 h and frequency responses were recorded every half hour. Fig. 3 represents 3 curves in the following time intervals: 1 – 0.5 h; 2 – 1 h; 3 – 1.5 h. The layer piezostack fourth 4 curve shows the response of the piezostack under normal conditions [2].

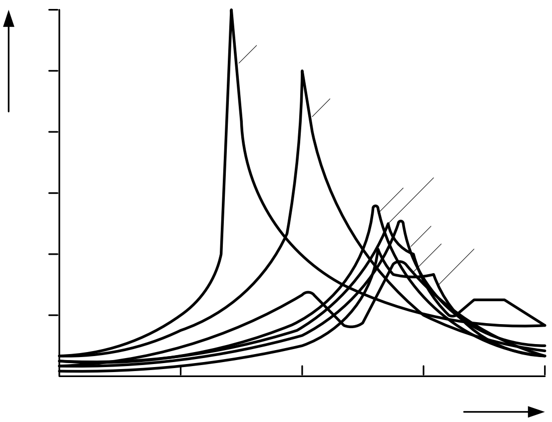


Fig.2. **Curve 1-frequency response under natural climatic conditions, 2–7 – frequency responses when temperature: –50°C**

The layer piezostack has been investigated under dynamic regime and without it. It should be noted that the dependence of the current flowing through the piezostack and depending on the frequency of piezoelements deformations makes it possible to choose the right power regimes. The temperature expansion coefficient of the transducer material should be unified with the layer piezostack temperature fluctuation because of complicated operation conditions and the fluctuation of environment temperature.

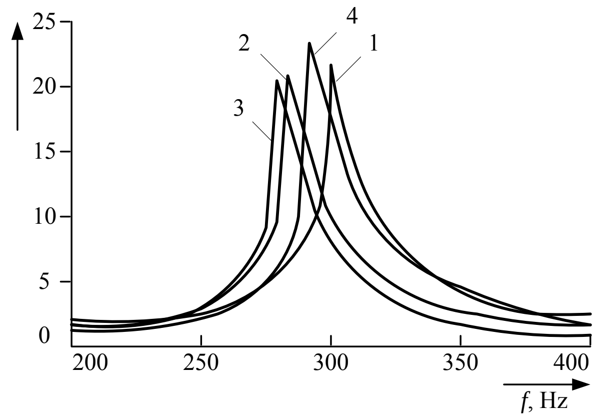


Fig.3. **Experiments when the temperature range is ±50 °C**

The experimental investigation of precision mechatronic systems (or their separate elements) by means of holographic interferometry enables one to obtain appreciably larger amounts of information about the surface deformation in comparison to traditional methods [3, 4]. The paper deals with the consideration of methods for determination of the characteristics of surface deformation of precision mechanical systems from the holographic interferograms of linked analysis of these characteristics obtained by using numerical techniques based on the theories of mechanical system under deformation and holographic interferometry. A multipurpose device has been developed for storing the holographic interferograms. It allows the application of various methods of holographic interferometry in order to obtain interferograms of excellent quality.

This study employs the double-exposure holographic interferometry technique for the quality assessment of surface deformation. The essence of this technique is the recording of holograms of two objects (being in different conditions, initial and deformed, for instance, before and after increase of voltage) on the same layer of a light-sensitive photographic plate. Upon having illuminated the hologram after two exposures with a copy of the reference beam, both beams, reflected by the object surface before and after the deformation, are restored at the same time. The results of their interference – the system of interferential bands is observed against the background of the surface of the object image, which provides information about changes in the object's status having occurred in the period between expositions.

Fig. 4 presents the structural diagram of a stand for experimental study of deformation processes in the mechatronic system (or in its separate elements) with the aid of holographic interferometry utilizing the method double-exposure.

The stand contains mechatronic system (or its separate elements) 1 and an operation mode control unit 2. The optical circuit of the stand includes a holographic installation with a helium-neon laser which serves as a source of coherent radiation. When passing through the beam splitter 6, the beam from the laser 1 splits into two mutually coherent beams. The object beam, reflected from the mirror 10, is split by the lens 11 and illuminates the surface of the working part of the mechatronic system 2 and, after reflecting from it, impinges on the photographic plate 4, which is fixed in such a way that the photographic processes

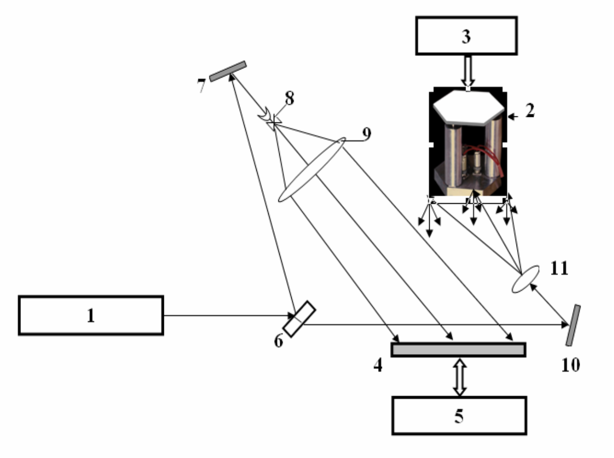


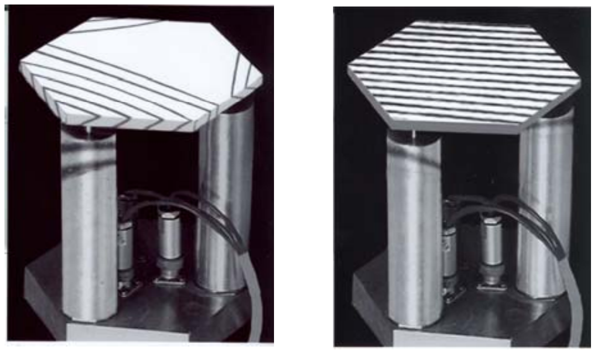
Fig.4. **Structural diagram of the holography stand: 1-laser, 2- mechatronic system, 3- control unit of mechatronic system operation, 4- photographic plate, 5- camera or video camera, 6- through the beam splitter, 7, 10 - mirror, 8- micro object-lens and spatial filtration diaphragm, 9, 11- lens**

of the plate processing (development, drying etc.) are allowed without changing its localization. During investigation this is enabled with the aid of holographic interferometry utilizing the method of real time. The reference beam, reflected by the mirror 7, via micro object-lens and spatial filtration diaphragm 8, and expanded by the lens 9, illuminates the photographic plate 4, where the interference structure is recorded. The object and the reference beams create interference in the plane of the photographic plate, and during exposure a constant in time three-dimensional interference structure is generated and recorded in as a hologram. In order to reconstruct the image, the hologram is illuminated by the reference beam. The reconstructed interferential image is photographed with a camera or recorded with a video camera 5. Seeking to reduce the duration of exposure of the photographic plate 4 and to improve the reconstructed contrast of the interferential image, the top of the working part of the mechatronic system 2 was painted mat white.

During the experiment the surface of the working part of the mechatronic system 2 was illuminated by the object beam, whose incident angle with respect to the direction of a working part shift was around 45°. Based on the character of the obtained localization of interferential bands, optimum operation modes of the working parts surface of the mechatronic system 2 could be determined.

Fig. 5 a shows an interferogram when a control signal is sent only to one active control layer piezostack of the mechatronic system. In this case, even deformation of the working part surface in the operation area of the active layer piezostack is observed. Slight surface deformation in the operation areas of other active piezostack emerges due to conditions of their fixing onto the surface of the working part of the mechatronic system 2.

Fig. 5b shows an interferogram, when a control signal is sent to all active layer piezostacks of the mechatronic system whose uniform character of operation is selected experimentally. In this case an equal shift of the working part surface towards the normal direction has been observed.



a b

Fig. 5. **The mechatronic system with active layer piezostacks: a – one active layer piezostack, b-two active layer piezostacks**

Conclusions

Dynamic characteristics of each individual element of compound piezodrives have to be determined separately. When assembling the piezostack, piezoelements with similar characteristics have to be selected. The bifurcation problem of a piezodrive has been solved by evaluating piezostacks physical properties of piezoelements and sealing material. It has made possible to prove that piezostacks have a lot of static possibilities. The original solution of the mechatronic system enabled the choice of optimal initial stresses in layer piezostacks. The experimental investigation of piezostacks with layer packets have revealed the possibilities to optimize the design and materials for optaining maximum displacements. Holographic interferometry method used in the experimental work has strengthened the expressions of differential equations and was used for describing conclusions of the investigation.

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Pjezopaketų parametrų nustatymas holografinės interferometrijos metodu

Reziumė

Pjezopaketai iš sudėtinių elementų, kuriuos jungia rišamoji medžiaga arba smeigė, sudaro statiškai labai atsparią mechaninę sistemą. Tokia sistema naudojama mechatronikoje, kai reikia užtikrinti stabilumą, dideles apkrovas įvairioje temperatūroje.

Siekiant gauti optimalius aptariamos sistemos parametrus ir jiems nustatyti taikant įvairius būdus, taip pat holografinės interferometrijos metodą, šis nekontaktinis matavimo metodas leidžia gauti papildomos informacijos apie tiriamos mechaninės sistemos darbinio paviršiaus deformacijas.

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