MECHANICAL MEASUREMENTS

TEST EQUIPMENT FOR ANALYZING
THE DEFORMATION OF MODELS
OF THREE-DIMENSIONAL STRUCTURES

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Test equipment, forming part of a model of a complex rod structure in the form of a seven-story stack, consisting of a system of ferroelectric strain sensors and a data-measuring channel in which Fourier transforms of the deformation of the structure are obtained by a shock-excitation method is described.

Key words: three-dimensional rod structure, deformation, loss of stability.

We will define a complex structure as a mechanical system in which, when it is excited, unstable states arise, leading to nonlinear deformation processes. We will consider as nonlinear, sign-variable deformation processes and bifurcations in the form of “knocks” and “skips” in the stable state of the structure. The establishment of criteria for distinguishing states of a complex structure is based on experimental and theoretical investigations of its behavior and responses to natural and/or special excitations. It can be asserted that the detection and description of the effects of a loss of stable states in undamaged structures is also fundamental for its earlier diagnostics. In this paper, we consider the problems of designing instruments and testing procedures for analyzing the deformation behavior of a model structure when shock test pulses are applied to it and also the development of an algorithm and criteria for distinguishing the states of undamaged structures.

Formulation of the Problem. The majority of structures are made from components which, in technical mechanics, in a one-dimensional and two-dimensional representation, are defined as column, triangular, circular and square frames. Unlike the diagnostics of damaged structures and their components, when analyzing the stability of the whole undamaged structure [4, 5] a lack of clarity arises in the forms of the spectra of natural oscillations [1–3] in answering the following questions: how do coupled units behave before “collective stability” or stability due to structural connections is established, and how can the results of the strength and/or life of different components or individual tests on them be taken into account in order to take decisions on the stability (life) of the structure as a whole? To answer these questions, it is necessary to construct and prove criteria for identifying their stability (instability) as it applies to a set of typical models.

Experimental Procedure. To investigate the deformation and to estimate the stability of three-dimensional structures, we designed test equipment, consisting of a physical model of the structure in the form of a seven-story stack, a system of ferroelectric strain sensors, and a data-measuring channel.

A model of the structure in the form of a seven-story stack (Fig. 1) was welded together from 8 single square frames with a cross section of 4 × 8 mm with sides of 250 mm and 28 rods – supports with the same cross sections and a length of 250 mm with an overall mass of the structure of 3.6 kg. The figure shows the horizontal suspension of the stack by the narrow (4 mm) end sides of the frame. The rods are welded to the frame so that their “wide” sides are perpendicular to the vertical axis OY. The ratio of 1:2 of the narrow to the wide sides of the section used is due to the difference in generating transverse
and flexural deformation waves at the coupling joints of the stack. The structure was suspended on Kevlar threads. Two versions of the suspension of the stack were analyzed: “unfree” suspension and suspension on threads fastened to brackets.

**Dynamic strain ferroelectric sensors.** The main sensor is a ferroelectric Pb(Zr, Ti)O$_3$ film, approximately 3 µm thick, deposited by high-frequency sputtering [6] onto a metal foil substrate 40 µm thick. After the deposition of an upper aluminum electrode 0.1 µm thick onto the film, a stable polarized state with a piezoelectric modulus $d_{33} = 1 \cdot 10^{-10}$ C·N$^{-1}$ is produced in the film by the action of an electromagnetic field and temperature. The sensor has current leads and is hermetically sealed with K400 epoxy compound. The sensor is fixed to the test model with glue. The following estimates of the main characteristics of the sensor were obtained: the sensitivity to relative deformation with a minimum value of the signal of 10$^{-6}$ V is 5·10$^{-6}$, the dynamic range of the strain is 150 dB, the capacitance is 800 pF, the frequency range is $10^{-4}$–$10^{-8}$ Hz, the operating temperature range is –190°C – +200°C, the overall dimensions are $1 \times 1 \times 0.004$ mm and the mass is not greater than $10^{-3}$ g.

The sensors are attached at distances of 15 mm from the joining sections $A_1$, $A_2$, and $A_3$ (see Fig. 1) on the wide and narrow sides of the rods of the stack. Hence, two different sensor systems (SS) were produced:

$$SS_w = \{A^1, A^2, A^3\}_w = \{(S1; S2; S3)_1, (S4; S5; S6)_2, (S-A; S-B; S-C)_3\};$$

$$SS_n = \{A^1, A^2, A^3\}_n = \{(S11; S12; S13)_1, (S14; S15; S16)_2\},$$

i.e., the system of sensors $SS_w$, set up on the wide side of the structure, includes the sensors S1–S6 and S-A, S-C, and S-B, whereas the system of sensors $SS_n$ is represented by sensors S11–S16.

A block diagram of the information-measuring channel is shown in Fig. 2. Deformation vibrations $\sigma(t)$ of the structure, recorded at the location of the thin-film ferroelectric strain sensors as a change in the charge with time $q(t)$, are fed through an AVKT-6 vibration-stable cable to the input of an RSh2734E charge amplifier. From the output of the amplifier, the time-varying voltage $U(t)$ is fed to the first channel of an OTsZS02 digital oscilloscope based on a personal computer. The other channel of the oscilloscope records the time form of the construction shock excitation pulse. The triggering of the oscilloscope sweep is synchronized using the leading edge of the shock pulse. The analog to-digital signal conversion time was 1 nsec. An LA-n1.5PCI-14 data collection unit was also used for this conversion. In order to make it possible to achieve completeness and juxtaposition of the data when synchronizing the triggering and recording of the vibrations for each sensor, the maximum possible duration $\tau_{\text{rec}}$ of recording and minimum sampling duration $\Delta\tau$ was provided. The duration of a