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DETERMINATION OF OPTIMAL DYNAMIC CHARACTERISTICS OF SMART-STRUCTURES BASED ON THE ANALYSIS OF NATURAL VIBRATIONS

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New smart composite material technologies make good use of piezoelectric materials, which due to the presence of the direct and inverse piezoeffect may play the role of sensors or actuators. The most common function of smart-structures with piezoelements is their application for controlling the dynamic behavior of the system. The piezoelectric effect allows part of the mechanical energy to be converted into electrical energy, which can dissipate in the external shunt circuits. The latter may contain different combinations of resistive, conductive and inductive elements. Such systems suggest realization of a passive mode of vibration damping. However, in some situations the most effective approach is to use an active damping mode. A key to this approach is the use of some piezoelements (sensors) as the units providing information on the mechanical behavior of the system, while the other piezoelements (actuators) receive the electrical potential, which is formed as a preset function of the sensor state.

From the viewpoint of solid mechanics, the smart systems under consideration can be considered as piece-wise homogeneous deformable bodies consisting of elastic, viscoelastic, and piezoelectric materials with external electric circuits composed of resistive, capacitive and inductive elements and also of devices providing active mode of vibration damping. In this case, the optimal dynamic behavior of the system is defined by a rather large set of parameters: locations, of sensors and actuators, parameters of the units of the external electric circuits, topology options for external electric circuits, variants of realization of active damping.

Out of the parameters characterizing the dynamic behavior of the system, most important are the resonance frequencies and parameters specifying damping properties of the simulated systems. Damping properties of smart systems are estimated in terms of the resonance mode amplitudes and the rates of transition processes using the ANSYS packages or other known algorithms. In the first case the solution is searched for the problem of steady-state forced vibrations and in the second case – for the dynamic problem with initial conditions. In the case of finding optimal dynamic characteristics, these problems have a restricted effect due to the following reasons. To obtain the resonance mode amplitudes by solving the problem of steady-state forced vibrations one needs to solve the problem repeatedly for different frequencies of external loads. Furthermore, in the framework of steady-state forced vibration problem or the problem with initial conditions the obtained optimal solutions are related to the simulated variant of system loading.

In this study, the optimal dynamic characteristics of a smart-systems incorporating piezoelements and external electric circuits are found by solving natural vibration problem.

The problem considers a number of piece-wise homogeneous bodies consisting of elastic, viscoelastic and piezoelectric elements. The piezoelectric elements can be connected through the surfaces covered by electrodes to the current or voltage generators, or to an arbitrarily structured circuit consisting of the resistive, inductive and capacitive elements. The variational equation of motion for the examined system is formulated based on the constitutive relations of the theory of elasticity, viscous elasticity and quasi-static Maxwell equations. A solution to the natural vibration problem is searched in the following form

$$u_i\left(x_i,t\right)=\overline{u}_i\left(x_i\right)e^{-i\omega t}$$

where u_i is the component of displacement vector, $\omega=\omega_R+i\omega_I$ is the complex natural vibration frequency, ω_R correspond to the natural vibration frequency, ω_I characterizes the rate of vibration damping, $\overline{u}_i\left(x_i\right)$ are the components of the vector of natural vibration modes.

The problem was solved for a variety of boundary conditions depending on connections of different external circuits to piezoelements. Numerical implementation of the problem was carried out by applying the procedure of the finite element method.

For the examined smart systems different examples of computation and optimization of dynamic characteristics have been considered using the following optimization parameters: the values of mechanical characteristics of the system materials; geometries and locations of piezoelements; quantities that define specific boundary conditions and parameters of external electric circuits.

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