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Dynamic effects associated with structural in homogeneity of structures

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General Note

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ABSTRACT

Oscillations of mechanical systems consisting of absolutely rigid bodies interconnected by measles viscoelastic elements are considered. The problem is reduced to solving transcendental algebraic equations, which is solved numerically. It is established that an inhomogeneous system is a superposition of interacting oscillations of several normal coordinates, the most intense at close natural frequencies, leading to the intensification of dissipative processes in the system.

Key words: damping coefficient; settlement scheme; free vibrations; complex frequencies; integral relations.

1. INTRODUCTION

The use of attenuation of dynamic viscoelastic systems with two degrees of freedom, when studying problems [1,6,7], they are rarely considered in the scientific literature. At the same time, the tasks of protecting an object in the form of a solid body on two elastic supports are important for engineering practice, since the "beam" type systems are widely used in transport dynamics [4,5].

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Mechanical problem

The natural oscillations of mechanical systems consisting of S bodies are considered. ($S_к$ – tough, S_e – viscoelastic; $S = S_k + S_e$). Body systems are connected to each other and the base by mass less (or massive) viscoelastic elements. The viscoelastic properties of materials are described by Boltzmann – Volterra integral relations [1,5]. Some of the deformable elements may be elastic, in this case, the heredity nuclei describing the rheological properties of the elements are identically zero. A system in which the rheological properties of the deformable elements are identical (the hereditary kernels of the elements are equal to each other) will be called dissipative homogeneous, and a system with different rheological characteristics of the deformable elements dissipative heterogeneous [2].

2. THE MAIN PURPOSE OF THE WORK

Main purpose of the work is investigation of the dissipative (damping) properties of the system as a whole. With free oscillations, the decay rate quantifies the dissipative properties of the system: the higher the speed, the higher the dissipation. For a quantitative assessment of the dissipative properties of the system, two quantities are proposed: the minimum damping rate of the natural oscillations and the maximum resonance amplitude. The dissipative properties of the system are determined primarily by the damping characteristics of the elements [Ibid.]. This statement is true for dissipative homogeneous systems. And it is completely inapplicable to dissipative inhomogeneous systems. The concept of a global damping coefficient is introduced. Global damping characteristics of a dissipative inhomogeneous system as a whole, are determined not only (and not so much) by the viscoelastic properties of system elements, but by the interaction of vibrations of various Eigen forms, which are substantially determined by the structure, design, geometry, size, elastic connections, mutual arrangement of elements [4 , 5,6]. In this case, the real part of the complex natural frequency ω_R is the frequency of damped oscillations, imaginary ω_I – the damping coefficient of the system's natural oscillations.

3. PROBLEM DEFINITION AND SOLUTION METHODS

When formulating the problem of self and forced oscillations of the system, the principle of possible displacements is used, according to which the sum of the work of all active forces acting on the system, including inertia forces, is zero [3]. Let us analyze the dynamic coefficients for the dissipative inhomogeneous mechanical design of electronic equipment, shown in Fig.1. In fig. one

$\tilde{C}_m$ – operator rigidity of the spring, which has the form (m=1,2,3) [2]

$$\tilde{C}_m\varphi(t) = C_{0m}\left[\varphi(t) - \int_0^t R_{cm}(t-\tau)\varphi(t)d\tau\right], \quad (1)$$

$\varphi(t)$ – arbitrary function of time; C_{0m}- instant stiffness, $R_{cm}(t-\tau)$ – core relaxation. Next, applying the freezing procedure [Ibid.], We replace relations (1) with approximate

$$\overline{C}_m\varphi(t) = C_m\left[1 - \Gamma_m^C(\omega_R) - i\Gamma_m^S(\omega_R)\right]\varphi(t) = \overline{C}_m\varphi(t),$$

where $\Gamma_m^C(\omega_R) = \int_0^\infty R_{cm}(\tau)\cos\omega_R\tau\, d\tau$, $\Gamma_m^S(\omega_R) = \int_0^\infty R_{cm}(\tau)\sin\omega_R\tau\, d\tau$, respectively, cosine and sine are the Fourier images of the relaxation core of the material. As an example of a viscoelastic material, let's take a three-parameter relaxation core. $R_{cm}(t) = A_m e^{-\beta_m t}/t^{1-\alpha_m}$, having a weak singularity [ibid.]. The technical task is to vary the physically feasible limits, the rigidity of the deformable element, its size and mass, to achieve the maximum reduction in the amplitude of resonant oscillations.

For a system with a finite number of degrees of freedom, the variation problem reduces to a system of linear Lagrange equations of the second kind with complex generalized rigidity:

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$$\sum_{k=1}^{6N}(a_{jk}\ddot{q}_k+\overline{C}_{jk}q_k)=0, \qquad j=1,2,3,...6N \qquad (2)$$

where a_{jk} - components of a real symmetric matrix of generalized masses; $\overline{C}_{jk}=C_{R_{jk}}+C_{I_{jk}}$ - components of a complex symmetric matrix of generalized stiffness's; q_k - complex generalized coordinates (components of mass center displacements and angles of rotation of rigid bodies).

The solution will be sought in the form: $q_k=A_k\exp(-i\lambda t)$, где $\lambda=\omega_R+i\omega_I$ complex natural frequency, A_k - complex Eigen mode oscillation. The problem is reduced to a complex algebraic problem of Eigen values of a system of equations of the form

$$[M]\{\ddot{X}\}+[C]\{X\}=\{0\}, \quad (3)$$

where [M] is a square inertia matrix and [C] is a square stiffness matrix, which are nth-order symmetric matrices [3]. The elements of the stiffness matrix in:

$$\tilde{C}_{jk}\,\varphi(t)=C_{jk}\left[\varphi(t)-\int_0^t R_{cjk}(t-\tau)\varphi(t)d\tau\right].$$

The characteristic equation of the system of differential equations (2) is

$$\det[[M]\lambda^2+[C(\lambda)]]=0, \qquad (4)$$

where λ– complex characteristic number. The system (2) with degrees of freedom has characteristic indicators $\lambda_1,...,\lambda_{2n}$. If all characteristic exponents are the simple roots of equation (4), then the general solution of equation (2) will be equal to the sum of particular solutions of the form

$$\{X(t)\}=\sum_{k=1}^{2n}C_k\{W_k\}e^{-i\lambda_k t}$$

Here C_k – arbitrary complex constants, and W_k – numeric matrices are columns. Imagine the characteristic indicators in the form, $\lambda_k=\omega_{Rk}-i\omega_{Ik},\lambda_{n-k}=\omega_{Rk}-i\omega_{Ik},(k=1,...,n)$, where $\omega_{Ik}>0$ and $\omega_{Rk}>0$ – real numbers, called damping coefficients and the natural frequencies of the damped system, respectively. When there is no damping, all the roots lie on the imaginary axis. When, damping the roots is located near the imaginary axis. The corresponding eigenvectors satisfy the orthogonality conditions:

$$(\omega_R+\omega_I)X_R^T[M]X_I+X_R^T[C]X_I=0 \quad , \qquad X_R^T[M]X_I+\omega_R\omega_I X_R^T[M]X_I=0$$

where the index "t" means transposition.

The characteristic equation (4) is solved by the method of Muller [4]. A solution close to the conservative problem is made as an initial approximation. ($R_{cj}(t)=0$). The core of relaxation (1) in Take in the for

$$R_c(t-\tau)=\frac{Ae^{-\beta(t-\tau)}}{(t-\tau)^{(1-\alpha)}}.$$

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Cosine U_n^c and sine U_n^s images of this kernel are expressed by the formulas

$$U_n^c = \frac{A\Gamma(\alpha)}{(p^2n^2+\beta^2)^{\alpha/2}}\cos\left(\alpha\cdot arctg\left(\frac{p_n}{\beta}\right)\right), \qquad U_n^s = \frac{A\Gamma(\alpha)}{(p^2n^2+\beta^2)^{\alpha/2}}\sin\left(\alpha\cdot arctg\left(\frac{p_n}{\beta}\right)\right)$$

where $\Gamma(\alpha)$- gamma function $p = \operatorname{Re}\lambda = \omega_R$. Consider the natural oscillations of a system with two degrees of freedom (Fig. 1). The following parameter values have been adopted [ibid.]: $A = 0{,}048;\ \beta = 0{,}05;\ \alpha = 0{,}1;\ C_{01} = 1;\ M = 1$, instant stiffness C_{02} varies within $1{,}0 \div 5$. Two variants of mechanical systems are considered. In the first variant, all elements are viscoelastic (for operator stiff nesses $\tilde{C}_m$ springs $R_{cm}(t) \neq 0\ ,m = 1{,}2{,}3$)

$$R_{c1} = R_{c2} = R_{c3} = \frac{A\exp(-\beta t)}{t^{1-\alpha}}, \qquad A = 0.048, \qquad \beta = 0.05, \qquad \alpha = 0.1$$

The calculation results are shown in Fig. 2, a. Dependence of natural frequencies on C_2 the same as in the case of a homogeneous system, the corresponding curves coincide with an accuracy of up to 5%. As for the damping coefficients, their behavior changes radically: the dependence ω_1 from C_2 becomes no monotonic. Of particular interest is the minimum value of the damping coefficient at a fixed stiffness C_2:

$$\delta = \min_k\{-\omega_{Ik}\} \qquad k = 1{,}2{,}3{,}\ldots,n\,.$$

Magnitude δ determines the damping properties of the system as a whole. In the case of a homogeneous system, the value δ (let's call it the global damping coefficient) is determined entirely by the imaginary part, the smallest in modulus of the complex natural frequency. In the case of a heterogeneous system, the role of the global damping coefficient is depending on the magnitude C_{02}. The imaginary parts of both the first and second Eigen frequencies come out. "Role change" occurs at a characteristic value of C_{02}, when the real parts of the first and second natural frequencies are closest. The global damping coefficient at the specified characteristic value C_{02} has a pronounced maximum. This circumstance represents, in our opinion, a new mechanical effect, which can be formulated as follows: oscillations of the Eigen forms of a non-uniform viscoelastic system with similar frequencies mutually quench each other. Instant stiffness C_{02} is a geometrical parameter determined by the size of the element, and not the physical properties of the material. The main feature of the detected effect is the qualitative dependence of the dissipative properties of the system on its geometric parameters. Thus, the results obtained for the dissipative inhomogeneous viscoelastic structure under consideration are fully consistent with the solutions of the problem of free damped oscillations and confirm the fact of a sharp increase in the intensity of dissipative processes as the fundamental frequencies approach in inhomogeneous viscoelastic systems. At the same time, the role of theology is reduced both to damping vibrations and to mutually amplifying interaction of vibrations, various modes, which significantly increases the dissipative properties of the system as a whole. This effect of interaction of various forms of motion of continuous bodies has a fundamental perspective for the synthesis of dissipative properties and material-optimal dissipative heterogeneous engineering structures, building products, damping compounds, materials and composites of various vibration-proof systems and devices. To determine the physical nature of the detected effect, we write the equation of motion of the system with n degrees of freedom in the normal coordinates of the elastic system. In the case of a homogeneous system, all relaxation cores R_{cij} are the same: $R_{cij} = R$, so the generalized complex stiffness matrix is a positive definite real matrix multiplied by a complex scalar:

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$$\overline{C}_{ij} = C_{0ij}[1-\Gamma^{c}(\omega_R)-i\Gamma^{s}(\omega_R)]$$

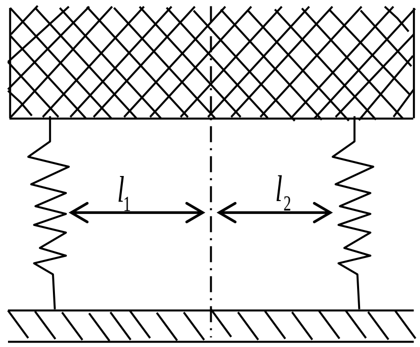

Figure 1 Design scheme

In the normal coordinates of the elastic problem, system (1) takes the form

$$\ddot{\theta}_n + \Omega_n^2\theta_n\left(1-\Gamma^c - i\Gamma^s\right) = \Psi_n \qquad (5)$$

where Ω_n - complex natural frequency of the elastic system; Ψ_n - generalized force corresponding to n - normal coordinate. System (5) fell apart on n separate equations. This means that the movement of a mechanical viscoelastic system is a superposition of independent normal oscillations that attenuate. And forced oscillations have a finite resonant amplitude. The main property of conservative systems — the possibility of exciting oscillations of one normal coordinate without exciting the rest — is fully preserved in the case of a homogeneous viscoelastic system. The situation changes radically in the case of a dissipative inhomogeneous system. Here, the generalized complex rigidity is the sum of two matrices - real and complex, which, generally speaking, are not similar. Three symmetric unmatched matrices (matrices of generalized masses, real and imaginary parts of the matrix of generalized rigidities) cannot lead C_{0k} to diagonal form by one any degenerate transformation. Therefore, in the case of an inhomogeneous system, the Lagrange equation in the normal coordinates of the elastic system has the form

$$\ddot{\theta}_n + \Omega_n^2\theta_n - \Omega_n^2\sum_{j=1}^{N}(\theta_{nj}^c + \theta_{nj}^s)\theta_j = \Psi_k \qquad (6)$$

where $\theta_{nj}^c, \theta_{nj}^s$ - nonnegative definitions of real matrices.

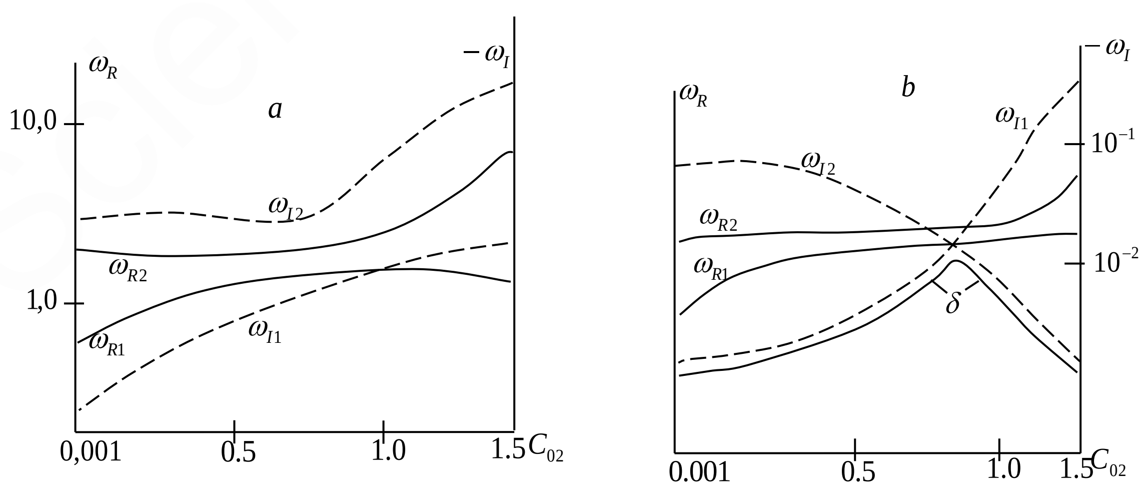

Figure 2 Dependence of complex frequencies on stiffness C_{02}

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System (6) consists of N related equations. Mechanically - this connectedness means the impossibility of exciting oscillations of a separate normal coordinate.

Each movement of the inhomogeneous system is a superposition of interacting oscillations of several normal coordinates, and this interaction of various normal coordinates, the most intense, at close natural frequencies, leads to the intensification of dissipative processes in the system.

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