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Theoretical-experimental method for determining the material damping properties based on the damped flexural vibrations of test samples

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Abstract

Theoretical-experimental method is proposed in this paper for determining the logarithmic decrement of vibrations based on the measurement of tip amplitude of the flat cantilever test samples during their damped vibrations at first resonance mode. Significant effect of external aerodynamic forces on logarithmic decrement is observed. Extensive theoretical and experimental studies were performed on the aerodynamic component of damping of oscillated flat strip plates. For the assessment of its contribution to overall damping of test samples during their free vibrations, large number of numerical experiments were carried out on two dimensional flow dynamics around the plate, in the light of which an approximated empirical formula is found. Present study is also covering the method to identify the elastic properties and amplitude dependencies of logarithmic decrement on deformation in accordance with the data of physical experiments performed with various series of test samples.

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Keywords: Theoretical-experimental method; internal damping; aerodynamic damping; experimental setup; test samples; damped flexural vibrations; computational fluid dynamics

1. Introduction

For the experimental determination of the damping properties of materials in the frequency range from 50 to 5000 Hz the standard test method ASTM E-756 [1] is widely used up to now, in which, by acoustic excitation, the dynamic

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behavior of cantilevered test samples of different structures is examined in frequency domain. If the concerned material is sufficiently rigid and isotropic, that is self-supporting, then uniform test beams from the damping material itself is used. However, the obtained results from this standard test method can not be regarded as applicable directly to the analysis of dynamical behaviour of any structure for the following two reasons: 1) the standard does not account the aerodynamical constituent of logarithmic decrement, which in most cases might be in the same order with internal damping properties of damping material itself. For the materials having low damping characteristics, aerodynamic damping can be regarded as critical constituent in determining the decay curve of flexural damped vibrations of test samples; 2) characteristics of damping materials by flexural vibrations of test samples are only comparative evaluation of damping properties, and can not be used in other conditions differing from test conditions. Hence, it is necessary to identify the valid material damping properties on the basis of internal damping characteristics of test-samples in their free flexural vibrations process.

2. Theoretical base

To determine the damping properties of the materials, cantilevered test samples of rectangular cross-section are used. Damping properties of test samples are defined with logarithmic decrement δ , which depends on the amplitudes of A measured at the tip point of specimen during its free oscillations. Relationshio $\delta(A)$ can be obtained by post-processing the experimental decay curve of damped vibrations in air environment in accordance with the method proposed in [2], in which, it was shown that damping properties highly affected by external aerodynamic forces: increase $\delta(A)$ with increasing width b of test sample. In order to exclude the effect of aerodynamic forces, a different approach can be used, in which a series of test samples with the same free length *L,* but different widths b are tested. This gives possibility to set a relationship of $\delta(A,b)$ and further $\delta^*(A)$ can be obtained by extrapolating that relationship down to the value $b=0$, which is necessary to identify the damping properties of concerned material.

It is possible to use theoretical-experimental method to find relationship $\delta^*(A)$:

$$\delta^*(A) = \delta(A) - \delta_a \tag{1}$$

where $\delta(A)$ logarithmic decrement of test-samples in air for finite width of beam *b*; δ_a - computational aerodynamic component of logarithmic decrement defined by empirical formula [3]

$$\delta_a = b\rho_f F_A / h\rho, \quad F_A = \frac{6.14}{\sqrt{\beta}} + 7\sqrt{k}\,\frac{\xi^2}{\xi^2+3.2}, \quad \beta = \frac{b^2 f}{\nu}$$
$$\xi = k[2 + 1.78\ln\Delta - (0.54 + 0.88\ln\Delta)\ln\beta], \quad k = \frac{A}{b}, \quad \Delta = \frac{h}{b} \tag{2}$$

Here A – amplitudes of tip point deflections measured in free vibration of test sample at the first flexural resonance mode; h – thickness of test sample; ρ – density of material; f – frequency of flexural vibrations in Hz; $\nu = 1.5\cdot 10^{-5}$ m^2/s – kinematical viscosity of air with density $\rho_f = 1.29$ kg/m^3.

Damping properties of concerned material is determined by logarithmic decrement δ , which depends on the amplitudes of the deformation ε_0. For the representation of this dependency, n-th order polynomial

$$\delta(\varepsilon_0) = \sum_{k=0}^{n} c_k \varepsilon_0^k \ . \tag{3}$$

Identification of damping properties is performed by searching coefficients of polynomial (3) through the dependency of $\delta^*(A)$ minimizing the objective function