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CONSIDERATIONS IN APPLYING DAMPING COATING MATERIAL PROPERTIES DETERMINED FROM BEAM TESTS TO THE CONTROL OF PLATE VIBRATION PROBLEMS

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INTRODUCTION

The use of viscoelastic damping material in layered coatings is an important alternative for the control of vibrations in complex structures. In the design of vibration control solutions, estimating the amount of vibration reduction which may be achieved depends on an accurate understanding of the damping layer material properties. While damping layer properties are usually derived from tests using vibrating beams, actual structures such as plates are more complex in the nature of their vibration. Also, beam test boundary conditions and vibration mode shapes seldom match actual inservice conditions.

The question as to how effectively damping layer material properties supplied from manufacturer's beam tests can be used in estimating the results of more complex problems arises and is the subject of this paper. In examining the question, comparison is made between the use of beam tests and vibration tests which employ a flat plate to extract damping layer material properties. In addition to the examination of experimental data, use is made of an energy based model which includes structural mode shapes to establish the relationship between the performance of damping layers in simple applications and more complex inservice situations.

GENERAL APPROACH

The vibration of thin elastic plates with thin elastic layers bonded to the sides has been considered through the use of an energy approach [1] which describes the Rayleigh quotient for the system

$$\omega^2 = \frac{U}{T} \tag{1}$$

where $\omega^2 T$ is the maximum kinetic energy of the system and U is the maximum strain energy of the system.

The correspondence principle of Bland [2] allows one to replace the elastic modulus of the added layer with a complex modulus as would be the case with viscoelastic layers. The resulting real part, ω_r, of the value of ω is the natural frequency of vibration and the loss factor at ω_r is given by

$$\eta(\omega_r) = \frac{\mathrm{Im}(\omega^2)}{\mathrm{Re}(\omega^2)} \tag{2}$$

EDGE FREE PLATES

In comparing the results of beam tests and plate tests, use is made of an edge free plate without a baffle to minimize acoustic radiation effects below the coincidence frequency. Equation (1) in the case of one side of the plate being fully coated with an unconstrained layer, can be expressed as

$$\omega^2 = -\frac{D_1\ (I_1 - 2(I-\nu_1)I_3 + (A+C)I_2 + (B+F)I_4)}{(\rho_1 h_1\ I + \rho_2 h_2)\ I_5} \tag{3}$$

where

$$I_1 = \iint_{A_1} (\nabla^2 w)^2 dxdy \qquad I_2 = \iint_{A_1} (\nabla^2 w)^2 dxdy$$

$$I_3 = \iint_{A_1} G(w)dxdy \qquad I_4 = \iint_{A_1} G(w)dxdy$$

$$A = 3(1 - 4\ \overline{H} + 4\overline{H}^2) \qquad B = -2(1-\nu_1)A$$

$$C = 4\overline{e}\ (\overline{h}^3 + 3\overline{h}^2\ \overline{H} + 3\overline{h}\ \overline{H}^2)(1-\nu_1^2)/(1-\nu_2^2) \qquad \overline{h} = h_2/h_1$$

$$F = -2(1-\nu_2)C \qquad I_5 = \iint_{A_1} w^2 dxdy$$

A_1 is the area of the plate, w is the deflection amplitude, G(w) is the Gaussian curvature, $\nu_{1,2}$ is Poisson's ratio of the plate and layer respectively, $\overline{H}$ is the distance from the plate-coating interface to the neutral surface divided by the plate thickness h_1, h_2 is the layer thickness, $\rho_{1,2}$ is the area density of the plate and layer respectively, and D_1 is the plate flexural rigidity.

For thin, flexible coatings, assuming ν_2 is the same as ν_1, simplifies the analysis without undue loss of accuracy. A subsequent rearrangement permits one to solve for the layer viscoelastic dynamic modulus of elasticity and loss factor by substituting experimental values of damped and undamped natural frequencies and the loss factor for the damped plate-layer system.

EXPERIMENTAL WORK

A series of tests were conducted to extract damping layer material properties from an edge free plate and from a series of cantilever beams. Beam dimensions were consistent with [3] while the stainless steel plate was 46cm by 46cm by .12cm thick. The damping layer was of the type EAR C-2003, .16cm thick.

Resonant frequencies and system loss factors as well as experimental mode shapes were obtained using impulse testing techniques as in [1] for both the plate and beam specimens. Emphasis in the work was on the lower modes of vibration below coincidence.

CONSIDERATION OF FINDINGS

Natural frequencies and mode shapes for the uncoated plate were compared to those predicted by Lessia [4]. It was noted that in particular for the plate in question, the third experimental mode shape deviated significantly from the circular form predicted by Lessia.

To illustrate the findings, Figure 1 shows a comparison of layer material loss factor derived from beam and plate tests data and the analytical approach described before. Agreement is good except for the plate mode at 35 Hz. This was, in fact, the third mode which deviated from theory. As analytical mode shapes were used in the calculations to produce the values of Figure 1, the results at 35 Hz are in error as compared to reality. This is included to illustrate the importance of the mode shape in the interactive effect of layered coatings and vibrating structures in the lower modes of vibration.

Figure 2 illustrates the loss factors of either the combined beam-layer or plate-layer systems. The variation in system loss factor may be significant depending on the structural and vibration mode environment in which the damping layer is employed.

CONCLUSIONS

The properties of viscoelastic damping materials may be obtained from either two-dimensional plate tests or one-dimensional beam tests provided that at a given frequency consideration is given to the respective mode shapes involved. Conversely, system loss factors data for beams with damping layer treatments should not be applied to more complex applications without giving consideration to the differences in mode shapes and other geometric dissimilarities which might be present. The energy based model of [1] accounts for individual structural characteristics and may be used in the estimation of a variety of damped structural vibration problems including both testing and design.

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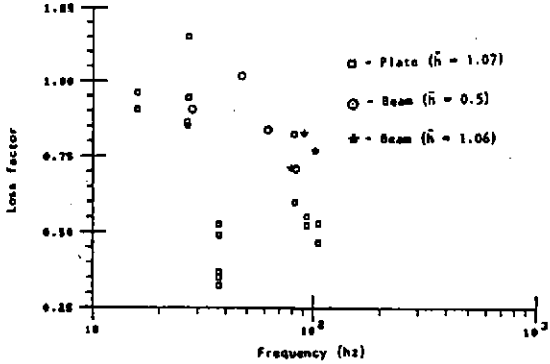

Fig. 1 Layer loss factors from plate and beam tests

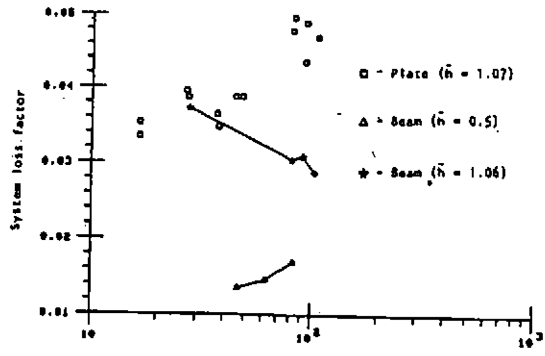

Fig. 2 System loss factors for plate and beam tests

*Sponsored by the U.S. Navy under Contract No. N00024-81-C-5337 to Florida Atlantic University.