Optimal use of polymetric materials in vibrating beam systems with the consideration of temperature and frequency effects.

Li CHENG , Guy PLANTIER(*) and Marc RICHARD

Mech. Eng. Dept., Université Laval, Québec G1K 7P4
(*) Mech. Eng. Dept., Université de Sherbrooke, Québec J1K 2R1

1. INTRODUCTION

Sound and vibration damping plays a critical role in numerous aspects of engineering and is increasingly addressed by legislation as well. The most commonly used damping materials are polymetric whose viscoelastic properties change a lot with temperature and working frequency. Suprisingly enough, this last point, which constitutes the main interest for chemists, has not received enough attention from researchers and engineers designing better damped structures. Quite often, the mechanical characteristics of these materials are considered to be constant. Another important problem to be tackled is the optimal use of these materials. In fact, numerous practical restrictions such as weight, cost and maintenance facilities demand that the structures be damped with partial damping coverage.The question is how to get reasonable damping performance without adding too much weight to the structures.

Theses two fundamental problems are tackled in the present work on a beam structure. First, a brief review is given to summarize the characteristics of typical polymers. Second, a preliminary model consisting of a partially covered beam is presented. The established model allows the consideration of the real variations of the characteristics of the damping materials with temperature and frequency. An iterative procedure is developped to calculate the damping factors of the whole system. Third, numerical results are presented and analyzed to show the effects of several parameters such as temperature, thickness, position, expansion of the covering layer and so on. Finally, some experimental results supporting the partial findings of the present work are illustrated. The established model presents the advantage of being sufficiently accurate and fast, and consequently constitutes the first step towards a complete model in which the optimization procedure will be included.

2. THEORY

2.1 Polymer materials

The temperature and frequency dependence of viscoelastic polymetric materials is relatively well known in the literatures [1]. Under some circumstances, the variation of the characteristics of these materials is so great that mechanical engineers have to take them into account. Two obvious observations justifing this statement are for example, mechanical systems such as space structures which suffer great temperature variations and structures driven by broad frequency excitations. Vibration damping in polymers is mainly dominated by the glass transition occuring in the amorphous portions of the polymer. For a given material, the glass transition indicates the frequency and the temperature at which the damping peak is a maximum. In the present work, the hard tan damping sheet manufactured by E.A.R (SD-40PSA) is used. The complex young's modulus comprising storage modulus and loss modulus is supposed to be frequency and temperature dependent. Measured data from the manufacturer [2] are directly used.

2.2 Theoretical model and formulation

The model investigated is a beam in flexural motion which is partially covered by an unconstrained viscoelastic layer. The beam is supposed to have an elstic supporting at each end. The position and the expansion of the layer are adjustable parameters in the model (fig.1).

The problem is formulated using the variationnal principle associated with the Rayleigh-Ritz method based on the following assumed displacement field [3]:

$$u(x,z)= -(z-h(f)+e_1/2)\frac{\partial w}{\partial x}$$
$$v(x,z)= 0$$
$$w(x,z)=w \quad , \qquad (1)$$

in which u,v and w are the displacements of the beam along x,y, and z axes respectivelly; $e_1$is the thickness of the beam. h(f) can be calculated as follows:

$$h(f) = \frac{e_1^2E_1+e_2^2E_2(f)+2e_1e_2E_2(f)}{2(e_1E_1)+e_2E_2(f))} \qquad (2)$$

In the above expression E_1 is the Young's modulus of the beam , $E_2(f)$ and e_2 are respectively the storage modulus and the thickness of the viscoelastic layer. e_2 is equal to zero for the noncovered portion.

The variationnal principle is applied to the system with the following trial function:

$$w = \sum_{K=0}^{n} a_k(2x/L)^k \quad . \qquad (3)$$

This approach leads to the following system equation:

$$[S]\{a_k\} = \{f_k\} \qquad (4)$$

Two types of problem can be solved by using the established model: the dynamic response of the beam driven by a point-force can be obtained by solving system(4) ; free vibrational analysis of the structure can be done by neglecting the terms in the system (4) corresponding to the excitation, the solution of this eigenvalue equation yielding the natural frequencies together with the modal damping factors.

Special attention should be paid to the treatment of the eigenvalue problem due to the fact that the system matrix [S] in which the modulus of the viscoelastic material is involved is frequency dependent. For this purpose, an iterative process is developped, the essence of which is as follows: For each seeked mode, a starting trial frequency ω_0, which is necessary to determine the modulus of the viscoelastic material and consequently the matrix [S], is used. Then with the known system matrix [S], the eigenvalue $\omega_R(1+j\eta)$ of the corresponding mode is calculated by using any standard procedures. The operation repeats itself by adjusting the value of ω_0 until $|\omega_0 - \omega_R| < \zeta$, with ζ being a sufficiently small quantity. In this case, ω_0 is the natural frequency of the structure and η the corresponding loss factor. The starting trial value used in the calculation is the natural frequency of the corresponding undamped beam.

3. PRINCIPAL FINDINGS

1). Experiments are carried out with a free-free aluminium beam(length 0.5m and thickness 4mm) covered by a layer of 1mm thickness over two-third beam length. Comparison between the measured values and the calculated ones in terms of ω and η shows excellent agreement.

2). The consideration of the frequency variation of the polymers introduces a non-negligable weighting on the modal analysis considering the material characteristics to be constant. This is particulaly true at the vicinity of the glass transition.

3). The modal damping factors of the system depend sensitively on the working temperature. The temperature affects also the stiffness of the system via the modification of the storage modulus of the viscoelastic layer, consequently clear shift of the resonance frequencies is observed.

4). The layer position is shown to affect strongly the damping factors of low-order modes for which the wave length is long. However the high-order modes seem to be less sensitive to the layer position.

5). With the assumption of equal mass added to the beam by the viscoelastic layer, the expansion of the layer is shown to play an important role in optimizing the damping perfomance. The fully-covered beam is seldom, if ever, the best solution for all configurations tested in the present work. This observation justifies the necessity of elaborating an optimization process.

REFERENCES

1. B. Hartmann, Polymernews, 16,134-141, 1991
2. Technical report, E.A.R
3. L. Cheng and J. Nicolas, J. Acous. Soc. Am. 91, 1504- 1513, 1992.

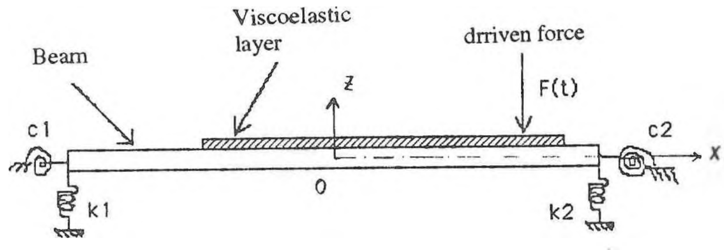

Fig.1 Investigated beam structure.

Frequencies in Hz

Mode	calculated	measured	difference in %
3	95.63	95.82	0.2
4	265.53	264.64	0.3
5	521.35	520.85	0.1
6	863.33	856.65	0.8
7	1294.78	1285.45	0.7
8	1813.06	1792.51	1.1
9	2416.68	2393.00	1.0

Damping factors in %

Mode	calculated	measured	difference in %
3	0.999	1.124	12.5
4	1.000	0.933	6.7
5	0.988	0.954	3.4
6	1.131	1.235	9.2
7	1.117	1.123	5.4
8	1.135	1.250	10.1
9	1.170	1.27	8.5

Comparison of the measured and calculated natural frequencies and damping factors.

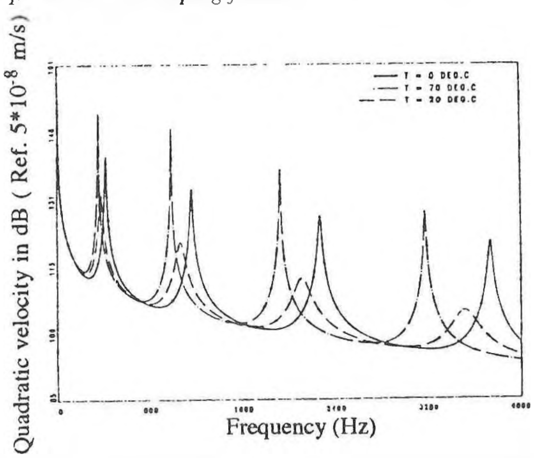

Fig.3 An example of the forced response of a partially covered beam working at different temperatures.

ACKNOWLEDGEMENTS

Authors thank M. Ph. DECOURT for participaping the work during his four month's training period.