PASSIVE VIBRATION CONTROL USING VISCOELASTIC MATERIAL MODELED BY THE FINITE ELEMENT TECHNIQUE

Júlio César Silva de Souza, julioeagricola@yahoo.com.br
José Juliano de Lima Junior, limajr@unifei.edu.br
Federal University of Itajubá, Institute of Mechanical Engineering Cx. P. 50 - 37500-903, Fax: 0xx-35-3629-1148, Itajubá - MG, Brazil.

***Abstract**: This work deals with viscoelastic materials characterization, applied in beam like structures, can be used in finite element model. The damping is increased by the application of viscoelastic treatment coupled of the structure. It is performed experimental procedures of vibration testing in the structure with viscoelastic material. The structure is subjected to an excitation by means of an hammer impact. The dynamic responses is obtained in frequency response function (FRF) and in time in various positions of the structure. Mathematical modeling computationally implemented and the experimental results do not only allow to evaluate the performance of viscoelastic materials, in terms of reducing the vibration levels, but also validate the mathematical procedures for incorporation of viscoelastic damping in finite element models.*

***Keyword**: viscoelastic material, mechanical vibration, passive vibration control, finite elements.*

1. INTRODUCTION

Among the different strategies to control noise and vibrations of mechanical systems, the passive control techniques deserve attention by researchers due to its low cost and inherent stability. The fact of application of viscoelastic materials are present in several industry sectors, has meant that, currently, many studies are conducted in order to develop formulations and numerical models to describe the behavior this damping mechanism.

According FINEGAM and GIBSON (1999) because of the reduced of the system complexity required damping, passive damping techniques compared with active techniques are those that contribute most to improve the reliability of machines and structures. Furthermore, they are considered stable, secure and have low energy requirements as opposed to active control, which requires the use of amplifiers often quite complex. Thus, the combination of materials (metal or composite) with passive damping techniques, especially using viscoelastic materials, is an extremely interesting strategy in the design of complex structures of engineering, making them more efficient and reliable.

The analytical study of vibration control is relatively complex, which justifies the use of numerical techniques, treating the problem as a discrete problem. Among the different techniques of numerical modeling, the finite element method (FEM), has proved the most suitable for modeling of various structures, mainly because of its advantageous features of modeling flexibility and relative ease of numerical implementation. In addition, the FEM is now a very evolved engineering tool, whose potential and limitations are widely known or studied.

The FEM is the discretization of continuous systems, ie the division of the domain (system) into subdomains called finite elements of simple geometry (eg triangles and / or rectangles to the bidimensional analysis). These elements are connected to neighboring elements by points called nodal points or simply us. Within each element the values of fields of displacements at the nodes are calculated using the approximation functions (polynomial interpolation functions). Therefore, the unknowns of problem will became the values of the displacements at the nodes, these unknowns are known as degree-of-freedom elementary. With this, it is possible to realize the assembly of the arrays of elements to construct the matrices and the global vectors, according to the conditions of compatibility and equilibrium at the nodes shared by neighboring elements. Finally we impose the boundary conditions necessary for the resolution of the system of equations.

The result is a system of differential equations in terms of state variables. The solution of this system, in static or dynamic analysis, indicates the responses of variables to the equilibrium condition of the system. The choice of state variables is based on the nature of the problem.

This work deals with viscoelastic materials characterization, applied in beam like structures, can be used in FEM Model.

2. APPLICATION OF VISCOELASTIC MATERIALS IN THE DAMPING OF VIBRATIONS IN BEAMS SANDWICHES

The application of viscoelastic materials between the structure and constraint layer contributes significantly to the rising rate of damping of these structures, therefore, they has not structural function. As a result, the characterization of the energy loss of viscoelastic materials is important to obtain this increase in damping ratio. The viscoelastic material, when associated with the main structure, may be subject to deformation extensional or shear, depending on the way it is applied. The strategy that forces a shear behavior of viscoelastic material is pretty referenced in the technical literature by the name of sandwich beams, which consists of the interaction of a system of at least three layers: structure, viscoelastic material and the restriction.

The operation of the damper type sandwich beam is given by the action of the layer of restriction on the damper material, deforming by the shear when the structure is subjected to bending. Generally, it is used for the same restriction layer for structure material, being rigid enough to track the vibrating movements of structure and promote the deformation of the damper material. Thus, these deformations occur in the damper layer material resulting in the dissipation of vibration energy, and the consequent increase in the damping of the structural system (SILVA, 2007).

2.1. Viscoelastic Behavior by Finite Element Method

Consider the following finite element model of a structure treated with viscoelastic material represented by equation (1) in the frequency domain.

$$\left[\boldsymbol{k}^*(\omega,T)-\omega^2[\boldsymbol{m}]\right]\{\boldsymbol{u}(\omega)\}=\{\boldsymbol{f}(\omega)\} \tag{1}$$

Where $\left[\boldsymbol{k}^*(\omega,T)\right]$ is the complex part, and is the complex stiffness matrix of element that depends on frequency and temperature since the behavior of viscoelastic material is represented by the complex modulus.

Assuming that the structure is composed of elastic and viscoelastic elements, the global stiffness matrix of the structure can be decomposed as follows by equation (2):

$$\left([\boldsymbol{K_e}]+\left[\boldsymbol{K_v}^*(\omega,T)\right]-\omega^2[m]\right)\{u(\omega)\}=\{\boldsymbol{f}(\omega)\} \tag{2}$$

where $[\boldsymbol{K_e}]$ represents the stiffness matrix corresponding to purely elastic substructure, and $\left[\boldsymbol{K}^*{}_{\boldsymbol{v}}(\omega,T)\right]$ is the complex stiffness matrix of substructure viscoelastic. Assuming that for isotropic materials, the coefficient of Poison is independent of frequency and temperature, the complex modulus can be divided into imaginary and real stiffness. Performing the normalization, the stiffness matrix $\left[\overline{\boldsymbol{K}_{\boldsymbol{v}}}\right]$ given by equation (3) is independent of the frequency and temperature of the system.

$$\left[K^*{}_v(\omega,T)\right]=E^*(\omega,T)\left[\overline{K}_v\right]=E'(\omega,T)(1+i\eta(\omega,T))\left[\overline{K_v}\right] \tag{3}$$

Where the imaginary part of $\left[K_v^*(\omega,T)\right]$ represents the damping matrix proportional to the system. The implementation of the dissipative behavior of the material in most commercial finite element codes is accomplished through an equivalent damping matrix, formulated as follows in equation (4):

$$\left[C_{eq}(\omega,T)\right]=\frac{E'(\omega,T)\eta(\omega,T)}{\omega}\left[\overline{K}_v\right] \tag{4}$$

Thus, we obtain from the equation (5) the global equation of finite element structural harmonic subproblem:

$$\left([K_e]+E'(\omega,T)\left[\overline{K}_v\right]+i\omega\left[C_{eq}\right]-\omega^2[M]\right)\{u(\omega)\}=\{f(\omega)\} \tag{5}$$

2.2. Experimental testing

Based on the method described by ASTM Standard (FAISCA, 1998) was prepared a test rig to enable a cantilever beam experiment. The material used for the preparation of the beams is aluminum. The aluminum beams were fabricated at the Laboratory of Mechanics UNIFEI. The physical and geometrical characteristics of the beam tested are detailed in Table 1.

Table 1. Physical and geometrical quantities of simple beams.

ME	L [mm]	B [mm]	H [mm]	I [m^4]	Mass [g]
Aluminum	920	38	2	2.53. 10^{-11}	214.35
Aluminum and VM	920	38	3	8.55. 10^{-11}	250.73

VM - Viscoelastic Material.

To obtain the dynamic characteristics of the beam tests were performed using free vibration through, an impact hammer, and a laser vibrometer. The beam's modal parameters were obtained using the technique of logarithmic decrement. The responses in both time and frequency were obtained from analyzer SRS - Stanford Research Systems model SR 780. All tests occurred at a constant temperature of 23 ºC and relative humidity 70 %. Each resulting value is the average of ten tests, with five replicates, totaling fifty replicates for each test.

Later testing with the beam, a layer of viscoelastic material was applied, characterized by a ribbon-type Double-Side Acrylic Mass Model 287. Is shown in the Table 2 geometric characteristics of the material used.

Table 2. Physical and geometrical quantities of Double Face Tape.

Type	L (mm)	B (mm)	H (mm)
Double Face	920	19	1

Is shown in the Figure 1 the process of making of the viscoelastic material adhered to the aluminum beam. Was necessary to put two layers of the same to fill the entire area of the beam.

Figure 1. Fabricating the aluminum beam with double side tape.

2.3. Result and Discussion

Are presented, in Table 3, the first three vibration modes of the beam, considering aluminum and aluminum with viscoelastic material, respectively. The calculated values of logarithmic decrement, the damping factor, and system loss factor also are presented. The damping factor ζ have values between 0.014 and 0.100, which is representative of the behavior of an underdamped system. It is possible to verify that the loss factors η of the system increased significantly when using the double-sided ribbon acrylic mass. They values are characteristic of the viscoelastic material that have a great energy dissipation capacity. The loss modulus E'' of the aluminum beam ranged from 88.23 to 22,264 GPa and 32 to 6,811 GPa for the beam with viscoelastic layer.

Table 3. Results obtained in the laboratory.

ME	**Mode**	fn (Hz)	Δ	ζ	η
Aluminum	1st	2	1.02	$1.60X10^{-1}$	$3.25X10^{-1}$
Aluminum and VM	1st	2	1.36	$2.10X10^{-1}$	$4.35\ X10^{-1}$
Aluminum	2nd	12	$1.90\ X10^{-1}$	$3.00X10^{-2}$	$6.10\ X10^{-2}$
Aluminum and VM	2nd	11	$5.70\ X10^{-1}$	$9.10X10^{-2}$	$1.80\ X10^{-1}$
Aluminum	3rt	33	$7.10\ X10^{-2}$	$1.1X10^{-2}$	$2.20\ X10^{-2}$
Aluminum and VM	3rt	31	$9.00\ X10^{-2}$	$1.4X10^{-2}$	$2.80\ X10^{-2}$

Table 4 shows the calculated results of storage modulus, loss modulus and complex modulus. The storage module refers to the elastic part of the system.

Table 4. Calculated results.

ME	$fn(Hz)$	$E'[Gpa]$	$E''[GPa]$	$\|E\|[GPa]$
Aluminum	2	83.90	27.27	88.23
Aluminum and VM	2	29.67	12.90	32.36
Aluminum	12	2945.74	181.65	2951.33
Aluminum and VM	11	864.29	158.71	878.74
Aluminum	33	22258.86	505.88	22264.61
Aluminum and VM	31	6808.33	195.46	6811.14

It is observed by means of figure 2 that the behavior of the displacement amplitude varies with the natural frequency of the system and especially with the use of viscoelastic material attached to beam. With the use of double side ribbon, we see an attenuation of vibration and a drop in natural frequency of the system, which was already expected due to the increase of mass system and the characteristic of viscoelastic.

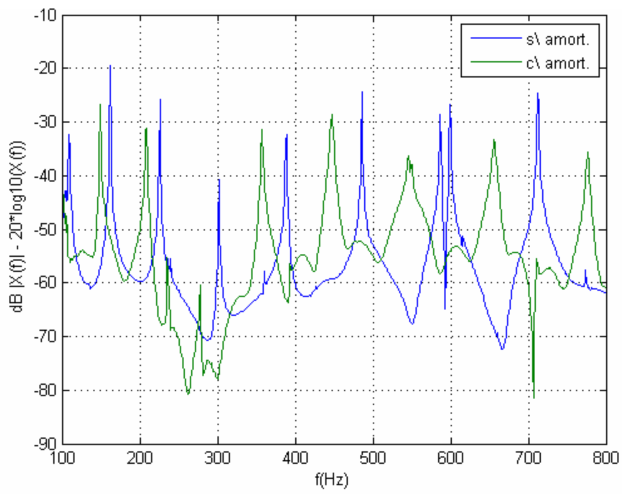

Figure 2. Frequency response for the tested beams.

In table 5 are shown some natural frequencies of the aluminum beam without damping. The beam was clamped at one end with a length L = 0.92 m, width B = 0.038 m and thickness H = 0.001 m, Young's modulus E = 70 GPa and density ρ = 2,700 kg/m^3. The first five natural frequencies of the model are presented in Table 5.

Table 5. Undamped natural frequencies.

Vibrate Modes	Calculated Frequency (Hz)	Frequency Measurement (Hz)
1	2.00	2.01
2	12.57	12.00
3	35.28	33.00
4	37.79	37.00
5	69.47	66.00

We Conclude that the results obtained using viscoelastic material, the beam has a great response with damping, showing the effectiveness of the response of the viscoelastic layer structure. The viscoelastic layer has changed the natural frequency of the structure and proved quite useful in reduction of vibration

3. ACKNOWLEDGEMENTS

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