euspen's 15th International Conference & Exhibition, Leuven, Belgium, June 2015
www.euspen.eu

Numerical and experimental analysis of viscoelastically damped structures

Frank Pasteuning[1], Walter Aarden[1], Mark Rijnen[2]

[1] *Philips Innovation Services, Mechatronics, 7, High Tech Campus, 5656 AE Eindhoven, The Netherlands*
[2] *Eindhoven University of Technology, Department of Mechanical Engineering, 2, Den Dolech, 5612 AZ Eindhoven, The Netherlands*

Frank.Pasteuning@philips.com

Abstract
To increase the vibrational and acoustic performance of structures, viscoelastic materials (VEM) can be used to introduce passive damping. Since the Young's modulus of VEM is frequency dependent, numerical dynamic analysis is not straightforward. This complicates design optimization and evaluation of different application methods for viscoelastic damping. In this study, numerical techniques for characterizing damping performance are explored and experimentally validated using a case study. Discrete damping elements and constrained layer damping are selected to efficiently damp an open aluminum box structure. The dynamics of the box are simulated using a finite element model, which includes frequency dependent VEM properties. This model is used to find designs that possess high damping while taking into account design constraints. The simulation results are experimentally validated using both modal parameters and frequency response functions (FRFs). Modal parameters are determined using an iterative method, while the FRFs are computed using interpolatory model reduction. Model based results and experimental results show good resemblance, even without model updating. This indicates that the considered simulation methods are a reliable tool in the prediction and improvement of structural damping with VEM.

Keywords: viscoelastic material, passive damping, structural vibrations, modal analysis, frequency response function, interpolatory model reduction

1. Introduction

In the high precision industry, demands on positioning accuracy are ever increasing. Unwanted structural vibrations hamper meeting these demands and can result in decreased performance. The vibrational performance of lightly damped structures can be improved by applying passive damping. Passive damping techniques are often preferred over (semi-) active methods, because they do not require power and are generally less complex and more robust. This study focusses on the introduction of passive damping with viscoelastic materials (VEM), a relatively simple technique with high damping potential. In literature, already quite some attention has been given to damping by means of VEM (e.g. VEM models: [1, 2], constrained layer damping: [3, 4], dynamic analysis methods: [5, 6]). Still, a numerical, experimentally verified, comparison of different VEM application methods for a specific structure of interest is not readily available. Furthermore, VEM damping is most effectively applied in an early stage of the design process, requiring methods to accurately and quickly predict the damping performance even for relatively complex structures. Since the Young's modulus of VEM is complex and frequency dependent, this is not straightforward.

This study proposes numerical techniques for predicting damping performance of viscoelastically damped structures (section 2). An iterative method is used to determine modal parameters and frequency response functions (FRFs) are computed using interpolary model reduction. The numerical techniques are validated experimentally in a case study (section 3). In this case study, optimized discrete damping elements and constrained layer (CL) dampers are compared for the efficient damping of an open aluminum box structure (section 4).

2. Modelling structures containing viscoelastic materials

Structures are regularly characterized dynamically using modal parameters (eigenfrequencies, damping ratio's, mode shapes) and FRFs obtained using a finite element (FE) analysis. FE analysis of structures that contain VEM is not straightforward however, since the Young's modulus of VEM is complex and frequency dependent (i.e. $E_v^*(\omega) = E_v(\omega)'(1 + i\eta(\omega))$, where E_v' is the storage modulus and η is the loss factor). This makes the system's stiffness matrix $\boldsymbol{K}$ frequency dependent:

$$[\boldsymbol{M}s^2 + \boldsymbol{K}(s)]\boldsymbol{q}(s) = \boldsymbol{F}(s) \quad (1)$$

Consequently, a standard, direct method for finding the system's eigenvalues and eigenmodes is not available. Instead, to compute the modal parameters, an iterative method is proposed. Here, ***K***(s) in (1) is considered frequency independent to obtain an estimate of the eigensolution. Next, for each mode separately, ***K***(s) is updated using a VEM model and the eigensolution is recomputed until it remains constant. The Modal Assurance Criterion (MAC) is used to extract the mode of interest from the complete set of modes for changing ***K***(s).

Because the system's stiffness matrix is frequency dependent, FRFs cannot be determined through standard modal superposition. Instead, they can be computed using interpolary model reduction. This model reduction technique uses a Petrov-Galerkin projection method to interpolate the full order MIMO transfer function. The used projection matrices span a rational Krylov input/output subspace created by using only a small set of interpolation points and tangential input/output directions [7]. The method is found to be as accurate as and computationally more efficient (>10x faster for the case below) than the harmonic analysis. The latter, although exact, requires excessive CPU-time and memory usage for large models and a high frequency resolution.

3. Case study design and realization

To validate the numerical techniques and compare different VEM application methods for damping, an aluminum box structure is considered (10.5 kg, 400 mm × 350 mm × 250 mm, and varying wall thicknesses). This is a simplification of common structural elements and is dimensioned such that it contains 13 well-separated local and global modes between 100 Hz and 1000 Hz. Analysis shows that discrete damping elements and CL damping configurations are most effective in damping the box structure. Figure 1 shows the final optimized design for these two damping configurations. To obtain realistic solutions, design constraints are applied to the mass added by the dampers (<0.5 kg per wall), eigenfrequencies (no or little reduction w.r.t. undamped) and commercial availability of the VEM. The discrete damper configuration uses four auxiliary beam structures to get deformation into eight VEM blocks (15 mm × 15 mm × 3 mm, Astrotech Norsorex® 46925). The damper dimensions and positioning are optimized for damping of the modes up to 1000 Hz. Typically, the VEM should be positioned such that it experiences large modal deformation. For the CL configuration, as a result of the varying wall dimensions, different CL thicknesses (0.3 mm - 0.5 mm, stainless steel) are used for each wall on top of the VEM layer (1 mm, Eriks RX® FPM).

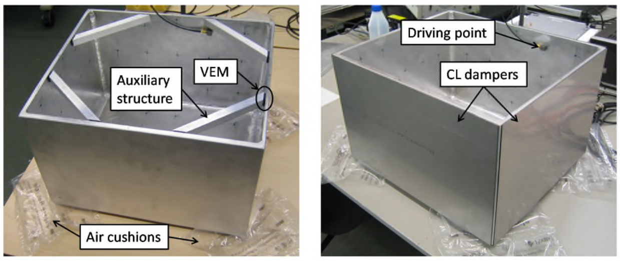

Figure 1. Realized box structures with discrete damping elements (left) and constrained layer dampers (right).

4. Comparison of numerical and experimental results

Using the numerical techniques described in section 2, the dynamic characteristics of the box damped with discrete and CL dampers are computed using a FE model (order 2e5 DoFs) which includes frequency dependent VEM properties.

For validation of the numerical results, the FRFs and modal parameters of the realized box structures are determined through an experimental modal analysis (in ME'scopeVES) using a roving hammer test. Figures 2 & 3 show a comparison between the measured and simulated results for the modal parameters and FRFs respectively. The simulated modal parameters match well with the measurements for at least the first 5 elastic modes of the damped structures. Since the predicted FRFs show good correspondence to the measurements over a larger range of modes, differences in modal parameters for higher order modes probably mainly result from difficulties in the extraction of modal parameters from the measurements (due to relatively high damping and overlapping modes). Other sources for differences are air entrapment below the CL dampers, errors in material properties and geometric modelling inaccuracies. Results could be further improved with a more detailed experimental modal analysis and accurate material property identification, both for the metal as for the rubber materials.

For this case, CL damping is found to give relatively high damping levels over a wide range of modes. Discrete damping elements add more damping, but only to a limited number of modes.

5. Conclusions

Numerical techniques have been proposed for predicting damping performance of (complex) viscoelastically damped structures. These techniques have been experimentally validated by comparing optimized discrete damping elements and constrained layer dampers for the efficient damping of an open box structure. The experimental validation shows that modal parameters and FRFs can be computed effectively using the proposed iterative method and interpolary model reduction method, respectively. These methods provide good results even without model updating and therefore prove to be a reliable tool in the prediction and improvement of structural damping with VEM.

References

[1] Jones D I G 2001 *Handbook of Viscoelastic Vibration Damping*

[2] Mead D J 1998 *Passive Vibration Control*

[3] De Lima A M G, Stoppa M H, Rade D A, Steffen Jr V 2006 *Shock and Vibration* **13** 545-558

[4] Sher B R, Moreira R A S 2013 *Composite Structures* **99** 241-254

[5] Zoghaib L, Mattei P -O 2013 *J SOUND VIB* **333** 887-900

[6] Li Li, Yujin Hu, Xuelin Wang 2013 *J SOUND VIB* **332** 3945-3956

[7] Antoulas A C, Beattie C A, Gugercin S 2010 *Efficient Modeling and Control of Large-Scale Systems* 3-58

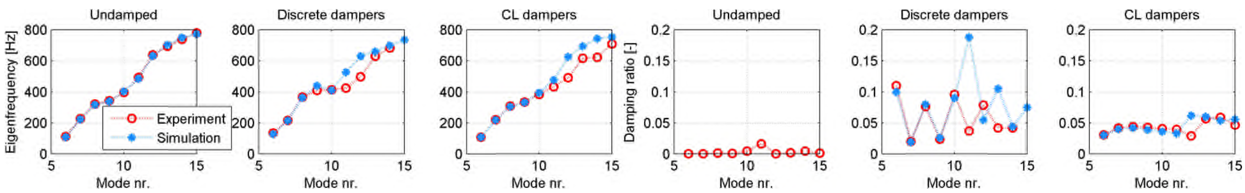

Figure 2. First 10 eigenfrequencies and damping ratios (excl. rigid-body modes) from experiments and simulations for different box configurations.

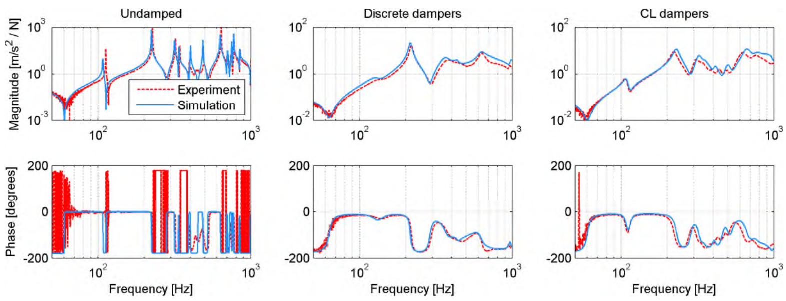

Figure 3. Driving point FRF (accelerance) from experiments and simulations for different box configurations.