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On the compromise between performance and robustness for viscoelastic damped structures

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Viscoelastic materials are commonly used for passive treatment in many applications. They exhibit a specific behavior depending on frequency and temperature, and thus damping performances can strongly vary in an uncertain environment for which these materials can be used far from their optimal nominal value. The problem studied in this paper is the compromise to find between damping efficiency and robustness to lack-of-knowledge when using structure with viscoelastic components. This question is illustrated on a damper made of a steel frame, considering two kinds of viscoelastic materials: the tBA-PEGDMA which is a viscoelastic material that exhibits very good performances but a very sensitive behavior according to frequency and temperature, and the silicone rubber SI 965 which is less efficient but whose behavior is less frequency- and temperature-dependent than the tBA-PEGDMA. In order to evaluate the performances, a complex eigenvalue analysis is performed on the finite element model of the damper, with different rheological material models. In a very original way, the temperature is introduced in the model to investigate its influence on the modal damping. In this context, and using the developed methodologies, a robustness study is performed using the info-gap theory to evaluate the modal damping performances for the two considered viscoelastic materials in an uncertain temperature environment. It is shown that the best design choice in terms of viscoelastic behavior really depends on the degree of lack-of-knowledge: robust and better performances can be obtained while quantifying the horizon of uncertainty.

1. Introduction

Viscoelastic materials are widely used for passive damping applications as for floor or dash panels [1] or for brake squeal mitigation [2] in automotive industry, in military aircraft and spacecraft industries [3]. They can be used as a free-layer or as a constrained layer treatment [4], as a multilayer laminate consisting of two skins with a viscoelastic core [5], or as a tuned viscoelastic mass damper [6]. Recent applications used such materials in assemblies to mitigate vibration transfers between parts inside structures, see [7]. When an excitation loading is applied to a viscoelastic material, dissipation occurs thanks to molecular rearrangements inside the material that lead to energy loss. These materials exhibit behaviors that depend on the temperature referred as the rubber phase and the glass phase separated by the glass transition. In the glass transition, the

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Nomenclature

Acronyms

FEM	finite element model
DOF	degree of freedom
GMM	Generalized Maxwell Model
CEA	complex eigenvalue analysis
FRF	Frequency Response Function
MAC	Modal Assurance Criterion
tBA-PEGDMA	tert Butyl Acrylate – Poly(Ethylen Glycol) Dimethacrylate

Main symbols

K	stiffness matrix
M	mass matrix
$K_{elastic}$	stiffness matrix of the elastic part of the system
K_{visco}	stiffness matrix of the viscoelastic part of the system
T_g	glass transition temperature
U	displacement field

damping produced by the viscoelastic material is highest than in other temperature ranges. Moreover, viscoelastic materials are also known to depend on frequency or mechanical loadings for instance. Thus, if temperature fields and excitation loadings are badly known, it is difficult to optimize the geometrical design and to perform the material choice. In [7], a damping map, in a space of Young's modulus and loss factor, with characteristics evolution as a function of the temperature is plotted. It allows to travel in the design variable map and to optimize the targetted solution. One strategy can consist in using stable materials with low variations over the temperature range, but this can be at the expense of strong damping efficiency. It appears relevant to take into account the inevitable uncertainties in a design stage to ensure both damping performance and robustness. This design needs to be able to simulate the dynamic behavior of structures including viscoelastic components, and many difficulties arise from the modeling of the viscoelastic behavior, and from the multiple dependencies of this kind of material, see [8].

In this context, the work presented in this paper aims at comparing the performances in terms of damping and robustness of two chosen viscoelastic materials introduced in a damper made of a steel frame and polymer inclusions. Firstly, a method to model structures including viscoelastic elements with finite elements is proposed. This strategy is based on a state-space formulation, on a Generalized Maxwell Model and the projection of the mass and stiffness finite element operators on an adequate basis, [9,2]. It allows to compute at reduced computation costs the complex eigenmodes and eigenfrequencies that are used to evaluate damping and modal performances. Secondly, the temperature dependency of different viscoelastic materials is highlighted and a very original way to build models to account for this dependency are proposed. Thirdly and finally, the damping efficiency of these materials is discussed in an uncertain context: the info-gap decision theory, which is well-suited for applications in which no probabilistic information is available, is used for that purpose. An application is performed on a damper made of a steel frame with viscoelastic inclusions.

2. Finite element modeling of a viscoelastic damper

This section aims at introducing both the use case and the theory basics of the simulation software especially developed for the application.

2.1. Description of the proposed study case

The study case consists in a damper made of a steel frame and viscoelastic elements added by melt-injection (Fig. 1) and patented by THALES (WO2014111534A1). This damper is introduced in on optical image stabilizer fixed under fighter jets and aims to achieve a sufficient damping level in all the directions of space during application phases. It is mainly used to reduce transfers in the radial directions. In comparison with the mass of the entire damper (red part), the elastomer patches constitute a ratio of 2%. The external ring is clamped on the optical devices while the internal ring is attached to the main frame. In this case, the vibration transmitted to the optics come from this structure. To accurately predict the physical behavior of the structure, this damper is modeled in details using the finite element method - FEM (Fig. 1): the total mesh consists in 49527 quadratic tetrahedral elements.

The finite element simulation of structures including viscoelastic elements is not common due to the dependence of these materials to frequency or temperature especially. The use of a classical numerical model taking into account only the elastic behavior of the system allows to simplify the simulations but leads to inaccurate results. One way to represent