Design and Optimization of Multilayered Acoustic Trims

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Introduction

Nowadays materials with a complex microstructure, like fibrous absorbers, open and closed cell foams [5],[2], viscoelastic solids, porous or viscoelastic composites, are used and combined for noise reduction. The acoustic effectiveness of absorber layers mainly depends on its effective material properties and its assembly.

The proposed optimization method consists of three steps: (1) The possible varieties of microstructured materials are analysed by computer simulation on the microscale, i.e. a certain set of boundary value problems is solved on the fully resolved microstructure. A following homogenization procedure computes the characteristic set of effective acoustic material parameters. (2) A database of these precomputed characteristic material parameters is used for the calculation of the rated sound transmission loss (DIN EN ISO 717-1) by means of the transfer matrix method (TMM) [1]. (3) The optimization algorithm changes the thickness of the layers in (2) to increase the rated sound transmission loss.

We will show examplary for viscoelastic composites, how the effective material parameters can be determined by simulation. We compare the acoustic behaviour of composites made of different microstructures and layer compositions.

The advantage of our method is that one can predict the behaviour of poro-elastic absorbers completely without the production of any blank parts or prototypes.

Effective viscoelastic material parameters

The basis is a dynamic mechanical analysis (DMA) of the viscoelastic behaviour for the matrix material of the composite and a stochastic model which represents the microstructure of the material realistically. The matrix material of the viscoelastic composite is a soft plastic. Since the DMA reveals, that soft plastic has a thermorheologically simple behaviour (Figure 1), the frequency dependent storage and loss moduli can be derived by the time-temperature superposition principle (TTS). For the simulation, the linear viscoelastic behaviour of the matrix material is described by a generalized Maxwell model

$$\mu(t) = \mu_0 \gamma(t), \text{ where } \gamma(t) = 1 + \sum_{j=1}^{N} \frac{\mu_j}{\mu_0} \exp\left(-\frac{t}{\tau_j}\right) \quad (1)$$

denotes the relaxation function. The moduli μ_i ($i = 1, \dots, N$) are obtained by fitting the complex modulus

$$\mu(f) = \mu_0 + \sum_{j=1}^{N} \mu_j \frac{\omega^2 \tau_j^2}{1 + \omega^2 \tau_j^2} + \mathrm{i} \sum_{j=1}^{N} \mu_j \frac{\omega \tau_j}{1 + \omega^2 \tau_j^2} \quad (2)$$

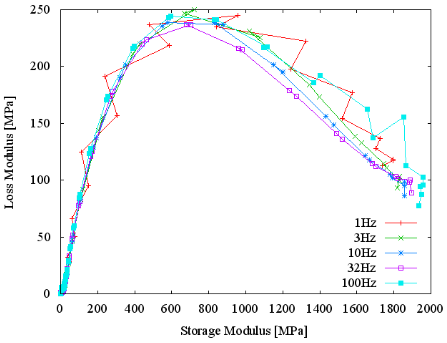

Figure 1: Cole-Cole diagram for a soft plastic.

of the generalized Maxwell-element to both the storage and loss modulus (of the matrix material) using the routine [9] (Fig. 2).

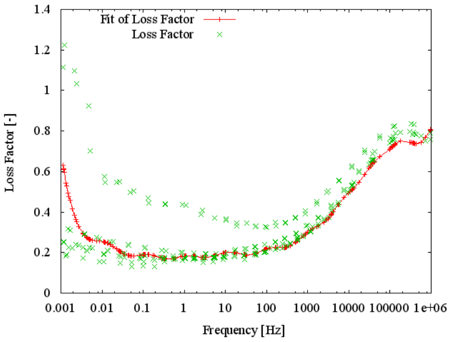

Figure 2: Fitting of the loss factor of the soft plastic.

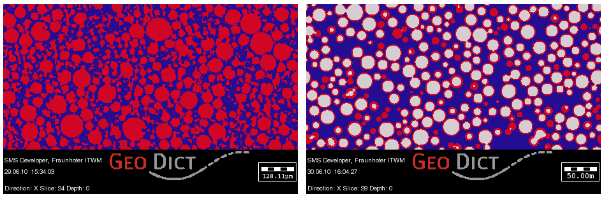

Figure 3: Tomography (left) and model (right) of the microstructure.

Homogenization

Using a tomography of a (existing) composite, a stochastic model of the microstructure can be derived (Figure 3) [8]. The experimental estimation of frequency dependent effective viscoelastic parameters for a viscoelastic composite is impossible for the whole set of parameters. Numerically they can be determined on the stochastic microstructure using the results of the DMA.

First, using the algorithm described in [4], multiple relaxation test are numerically performed for the composite. Secondly, using again the routine [9], the obtained normalized storage modulus is fitted by the normalized characteristic relaxation function (1).

This way we obtain a model for the (isotropic) viscoelastic behaviour of the porous absorber from which the effective elastic modulus can be computed according to Equation (2) and the loss factor of the porous absorber is simply defined as ratio of the imaginary and the real part of the complex elastic modulus $\eta(f) = \Im(\mu(f))/\operatorname{Re}(\mu(f))$.

Optimization

Variation of the parameters of the stochastic microstructure model

For real applications the material price is the most severe constraint. Since in our example of soft plastics with hollow glass spheres the glass spheres are a lot of cheaper than the plastics, the producer would like to increase the amount of glas spheres as much as possible (without reducing the rated sound transmission loss under a critical value). By changing the amount of glass spheres in the stochastic microstructure model, evaluating the effective viscoelastic material parameters and applying the transfer matrix method (TMM) we can give an estimation for the critical amount of glass spheres (see Fig. 4).

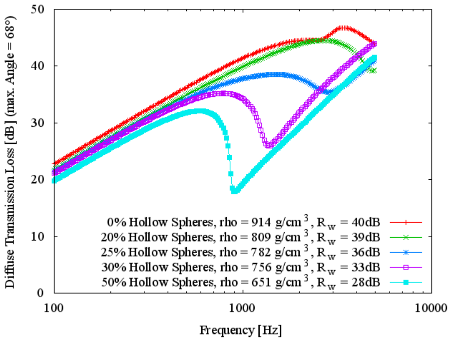

Figure 4: Transmission loss for the different microstructures made up of soft plasctics and glas hollow spheres.

Multilayer acoustic trims

Though it is desirable to use only one material (with complicated microstructure) to reduce the sound transmission this is not always possible, because additional constraints, like heat insulation, have to be fulfilled.

Using a database of precomputed characteristic material parameters and appropriate acoustic models (Delany & Bazley [6], Allard & Johnson [1], Biot [3]) the design can be improved (Table 1, Figure 5).

Summary and outlook

Our method for predicting the acoustic behaviour of porous absorbers can be applied to fibrous absorbers, open and closed-cell foams, viscoelastic solids or viscoelastic composites. By varying the parameters of the microstructure, the microstructure can be optimized with respect to a desired rated sound transmission loss. One can also optimize multilayered acoustic trims by changing their layer design and comparing the predicted rated sound transmission loss.

A	B	C	D
	10 mm Plastics	7 mm Plastics	4 mm Plastics
	3 mm Non-Woven	3 mm Non-Woven	6 mm Non-Woven
30 mm Plastics	9.34 mm Plastics	15.34 mm Plastics	16.98 mm Plastics
	3 mm Non-Woven	3 mm Non-Woven	6 mm Non-Woven
	10 mm Plastics	7 mm Plastics	4 mm Plastics

Table 1: Layer composition.

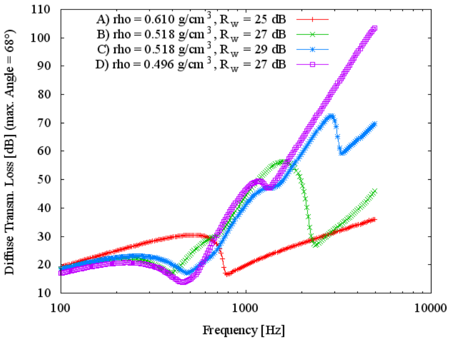

Figure 5: Transmission loss for the multilayered absorbers.

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