TRANSMISSION LOSS OPTIMIZATION OF MULTI-LAYER NOISE CONTROL TREATMENTS

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INTRODUCTION

The design of sound barriers is of utmost importance in several industries including automotive, aerospace and buildings. These barriers are typically made up of a decoupling layer sandwiched between a thin skin and a limp massive impervious layer classically known as a septum. As such, they may be considered as a double wall system. The decoupling layer is usually made up from a porous-elastic material such as cellular (e.g. polyurethane foam) and fibrous (e.g. glass fibers) materials. In designing sound barriers for multiple engineering applications, the engineer must select the type and geometric configuration of the barrier and decoupler materials to be used. This task necessitates a thorough understanding of the mechanisms governing the transmission loss of such systems together with an accurate data bank of the mechanical and acoustical properties of these materials.

The paper discusses the optimization of the diffuse field transmission loss through double-wall sound barriers with porous linings. The studied sound barriers are made up from a porous decoupling material sandwiched between an elastic skin and a septum, figure 1. The wave approach is used to calculate the transmission loss of the system [1,2].

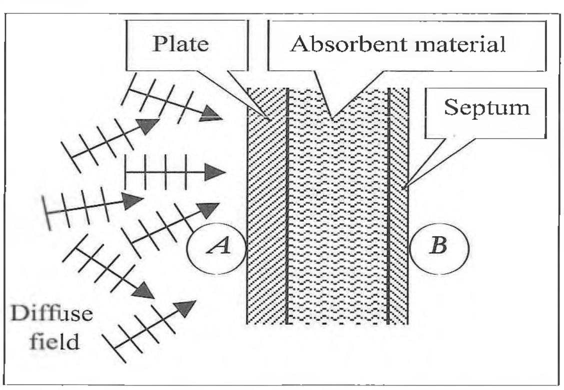

Fig.1. Plate – absorbent material – septum configuration.

OPTIMIZATION AND OBJECTIVE FUNCTION FORMULATION

This study aims at optimizing the frequency band averaged diffuse field transmission loss of the three layers system represented in figure 1 while imposing constraints on the weight and thickness of the system. Other variations on this objective include a combination minimum weight and transmission loss. However, in this latter case, both objectives are combined to form a single objective; no use of multi-objective algorithms is attempted. The band frequency averaged diffuse field transmission loss defined as:

$$TL = -10\log_{10}\left[\frac{\int_{f_{\min}^{i}}^{f_{\max}^{i}}\int_{\theta_{\min}}^{\theta_{\max}} |T(\theta,f)|^2 \cos\theta \sin\theta d\theta df}{\int_{f_{\min}^{i}}^{f_{\max}^{i}}\int_{\theta_{\min}}^{\theta_{\max}} \cos\theta \sin\theta d\theta df}\right]$$

where f_{min} and f_{max} are the lower and upper limits of the frequency band and $T(\theta, f)$ is the transmission coefficient, at frequency f, for a plane wave of incidence angle θ. Constraints are imposed on the weight of the system, as well as upper and lower bounds on the design variables. The optimization problem reads:

Minimize: $TL(X)$

Subject to: $\frac{W(X)}{W_{\max}} - 1 \leq 0$

$C_i(X) \leq 0$ i=1,Nc

Where X represents the vector of design variables, W represents the surface mass of the system, W_{max} represents a maximum specified weight, C_i represents the lower and upper bounds constraints on the design variables and N_c represents the number of these constraints.

Two optimization algorithms are studied and compared. The first is based on the Matlab implementation of the Sequential quadratic Programming algorithm [3]. The second is based on an in-house implementation of evolutionary algorithms. The design of this latter algorithm is problem dependent and allows the search of the whole design space for the global minimum [4]. Also, a combination of both algorithms is investigated to combine the advantages of both algorithms: locating the desirable region of the search space using the evolutionary algorithm and rapid convergence using the SQP algorithm in the reduced search space.

IMPLEMENTATION

The above optimization problem is implemented by combining the optimization engine (MATLAB or in-house) to an acoustic-indicator engine for the transmission loss calculation. The high frequency module of MNS/Nova is used for this part [5]. It uses the wave approach, which is essentially based on the representation of plane wave propagation in different media in term of transfer matrices [1]. This approach allows easily for multi-layers made up from a combination of elastic, porous-elastic and fluid layers. In a given layer, sound propagation is represented by a transfer matrix [T] such that $V(M_1) = [T]\, V(M_2)$, where M_1 and M_2 are two points set close the forward and backward face of the layer, respectively, and where the components of the vector V(M) are the variables witch describe the acoustic field in a point M of the medium. The derivation of the transfer matrices for solid, poro-elastic and fluid layers are detailed in [1,2]. Using continuity equations at the different interfaces, and the impedance equations in the source and receiving domains (assumed semi-infinite), a global system of equation is formed and solved for the reflection and transmission coefficients.

RESULTS AND DISCUSSION

In the first part of the paper the properties of the plate and septum are fixed and the optimization is limited to the properties of the porous layer. The aim is to tailor certain material properties of the porous layer (the flow resistivity) to achieve the desired minimum noise condition. However, contrary to previous work, constraints are imposed on the dependent variables of the porous layer (characteristic lengths) in order to keep the optimized solution realistic. Several types of problems are studied. Firstly, to test the used optimization approach, the porous layer is assumed to be fibrous and its flow resistivity is selected as the primary variable. Fibrous layers are classically modeled as a rigid frame porous layer and an empirical model is used to link the primary variable to the secondary variables used to define the porous layer within Biot-Allard theory [1]:

$$\sigma R^2 \rho_1^{-1.53} = 0.79*10^{-9};\ \alpha_\infty = 1;$$

$$\Lambda = \frac{1}{2\pi LR} \qquad \Lambda' = 2\Lambda \qquad L = \frac{\rho_1}{\pi R^2 \rho_m}$$

where σ enotes the porosity, α_∞ the tortuosity , Λ the viscous characteristic length, Λ' the thermal characteristic length, R denotes the radius of the fibber, ρ_m the density of glass and ρ_1 the density of the material.

Secondly, a foam layer is considered and once again the flow resistivity is used as the primary variable. To define the dependent variable, the viscous characteristic length is varied with the flow resistivity so that the form factor M is kept constant. The ratio between thermal and viscous characteristic lengths is fixed to 2.5. In such conditions, the intrinsic geometry of the skeleton is kept realistic. The other parameters are fixed and correspond to usual foam properties: porosity F = 0.98, $a_¥$ = 1.3 and skeleton density r_2 = 33 Kg/m^3. Finally, for a given prescribed maximum total thickness and weight, the thickness and properties of the foam and septum layers are used as the primary variables.

In all the above optimization problems, two frequency regions are considered in the objective function definition, a low frequency range B_1 that includes the double wall resonance frequency and a mid to high frequency range B_2.

We consider as an example the diffuse field transmission loss of a typical three-layer system made up from a foam layer sandwiched between a 0.92-mm thin steel plate and an EVA barrier with surface density 2.43 kg/m^2.

Figure 2 shows, in the case of the mid-to high frequency range, that there exists an optimal value of the flow resistivity for which the transmission loss is maximal. A detailed description, validation and interpretation of such results will be given at the oral presentation.

CONCLUSION

The paper investigates the transmission loss optimization of classical configuration in the automotive industry wherein a decoupling porous layer is sandwiched between the body sheet metal and a septum. Several optimization strategies and problems are studied and compared. The results discussed in this paper are preliminary. Detailed and more realistic results will be presented at the oral presentation.

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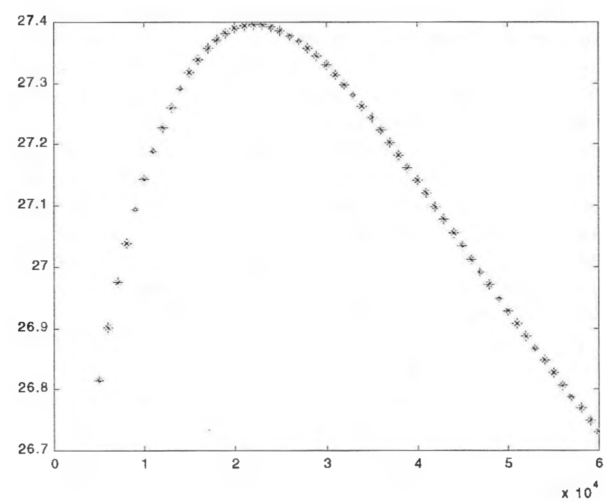

Fig.2. Optimization in middle to high frequency range for the foam material case.