ACTIVE CONTROL AND POROUS MATERIALS

PACS REFERENCE : 43.50.Ki

GALLAND Marie-Annick ; SELLEN Nadine; HILBRUNNER Olivier
Ecole Centrale de Lyon
Centre Acoustique du LMFA, UMR CNRS 5509
69134 ECULLY Cedex
France
Tel. : 33 4 72 18 60 13
Fax : 33 4 72 18 91 43
E-mail : Marie-Annick.Galland@ec-lyon.fr

ABSTRACT

This paper deals with two applications combining active control and porous materials : the first one concerns the development of a hybrid active/passive liner. The active control of its surface impedance is achieved by a simple active noise reduction at the rear face of a porous layer. Promising noise reductions have been obtained in flow ducts. The second application concerns the inverse formulation: applying active control at the rear face and measuring the front face impedance change allow us to determine the propagation characteristics of the porous material rapidly and by means of a unique set-up.

INTRODUCTION

In recent years, noise has become a crucial factor in the design of vehicles, especially in the automotive and aircraft industries. Many research programs have been carried out in order to design efficient noise reduction technologies. Conclusions often suggested that combined solutions are the most suited to cover the whole frequency range of the noise. Indeed, passive structures are adapted to reduce noise and vibrations for the high frequency contributions while active control technologies, even if not yet very employed in industrial applications appear to be the unique way to reduce the low frequency components. We have developed for nearly ten years a concept of hybrid absorbers, which combines passive properties of a porous material and active reduction of the pressure at its rear face. It aims at providing a targeted impedance predetermined to achieve the best noise reduction in the final application. Usually, two frequency ranges have to be defined for the utilization : at low frequencies, active control is on and allows to generate the same boundary condition (pressure cancellation) than the one realized in the well known quarter- wavelength absorber. At higher frequencies, active control is off and the air gap at the rear face is designed to achieve the targeted impedance. The porous material has to be first theoretically optimized in order to play this double role, and afterwards it has to be practically realized from existing samples. This combined use can be called “direct” because in these applications active control is used for obtaining a desired impedance thanks to the transfer through a porous layer.

We also develop the “inverse” process : active control is used for modifying the rear boundary condition while the surface impedance change is measured, allowing to identify the material properties. These two related methods are presented in this paper, with some typical results.

DESIGN OF A HYBRID ABSORBER

We present here the complete process for optimizing a hybrid absorber aiming at reducing noise in a laboratory set-up, the ECL flow duct called MATISSE (figure 1). Its simple geometry (in particular the anechoï c termination) allows to achieve precise comparisons with theoretical results. The design procedure includes the following steps:

- Calculation of the optimal impedance.
- Design of a well suited porous material. This stage should provide a compromise between a good noise reduction and an achievable active absorber. The optimization process is carried out through modeling the acoustic propagation inside a porous medium.
- Realization of a prototype of the active absorber and validation in the standing wave tube
- Tests in MATISSE facility (insertion loss and transmission loss measurements), and comparison with predictions.

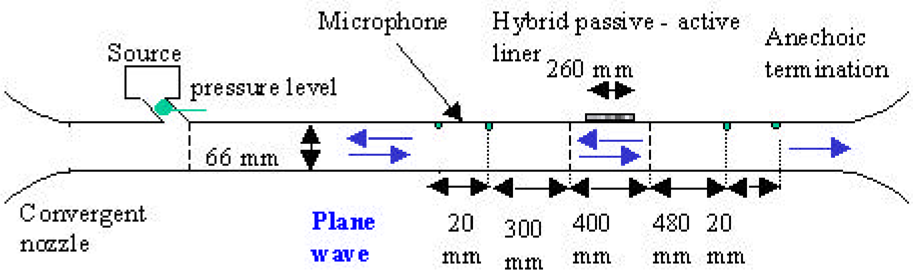


Figure 1: “MATISSE” experimental set-up

The basic principle of the hybrid liner has been presented and validated in a previous study [1]. It can be summed up as follows : the low frequency acoustic behavior of a porous material is mainly described by the flow resistivity (ratio between the pressure gradient and the velocity through a porous layer). If the pressure vanishes at the back face, the layer input impedance can be approximated by the flow resistance. Consequently, impedance control can be simply implemented by reducing the pressure at the rear face of a porous layer having well suited characteristics. The system we use is a first prototype developed in collaboration with METRAVIB in the context of the Brite Euram RANNTAC program [2]. Using a piezoelectric actuator as secondary source allowed us to achieve a thin active liner (thickness < 30 mm), which is efficient over a wide frequency range (figure 2). A larger absorber is built by joining several cells. Experiments have been carried out with either digital feedforward or analogue feedback controller.

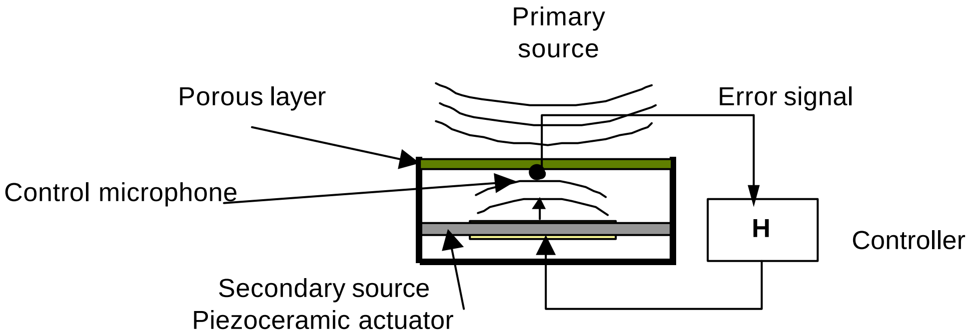


Figure 2 : One cell hybrid absorber

Firstly, the optimal impedance is calculated from simulation of the MATISSE test duct. Either analytical development based on modal expansion or numerical simulations by SYSNOISE have been used for determining the insertion or the transmission loss in the no-flow case. The optimal impedance is then deduced by scanning the complex plane and its evolution versus frequency is plotted on figure 3. It can be noticed that for very low frequencies, the best impedance value is closed to zero, what is coherent with the plane wave assumption. Indeed, the pressure cancellation is achieved in the whole cross-section when the wall impedance is assigned to zero. For higher frequencies, evanescent modes become less negligible and the real and imaginary parts depart from zero.

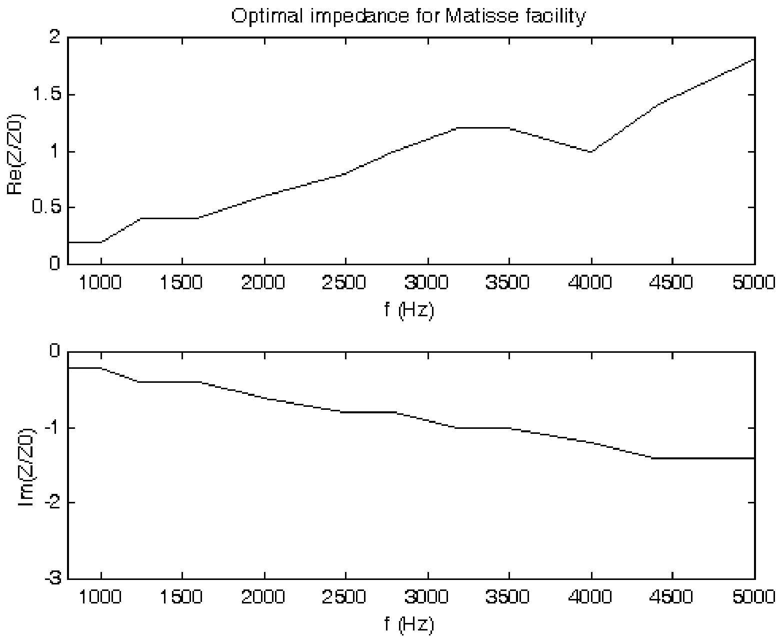


Figure 3 : Optimal impedance for the test duct MATISSE

The next stage should provide a compromise between a good noise reduction and an achievable active absorber. The optimization process is achieved through modeling the acoustic propagation inside the porous medium. Its main characteristics (thickness, resistivity, porosity, tortuosity,..) are determined to provide a surface impedance that approaches as close as possible the targeted one, when a pressure cancellation is applied at its rear face. Unfortunately, it is impossible to follow both real and imaginary parts with an existing material. The best compromise seems to be realized when the reactance remains close to zero and the resistance is close to the mean value of the targeted one on the whole frequency range. This can be achieved by using a high resistive material, such as a wire mesh. This theoretically pre-determined solution is then tested in a standing wave tube and the really achieved surface impedance is measured. This value is then introduced in the simulation of MATISSE and the expected insertion loss deduced. Finally, comparison is made with measurements carried out with the active absorber. We present in figure 4 the insertion loss obtained with two examples of a four-cells active liner. Active control was here achieved by means of the classical MIMO filtered-x LMS algorithm. The porous materials are wire meshes having a resistance successively close to Z0 and Z0/2, where Z0 is the characteristic air impedance. The measured and predicted curves of insertion loss are in very good agreement.

The complete design is thus demonstrated and a significant noise reduction is achieved at very low frequencies considering the weak extent of the treated surface. Compared to classical active noise technology (direct noise cancellation at one or several control microphones), and as already experimented [2], this system can be used without any change in the presence of a flow, due to the protection provided by the resistive layer.

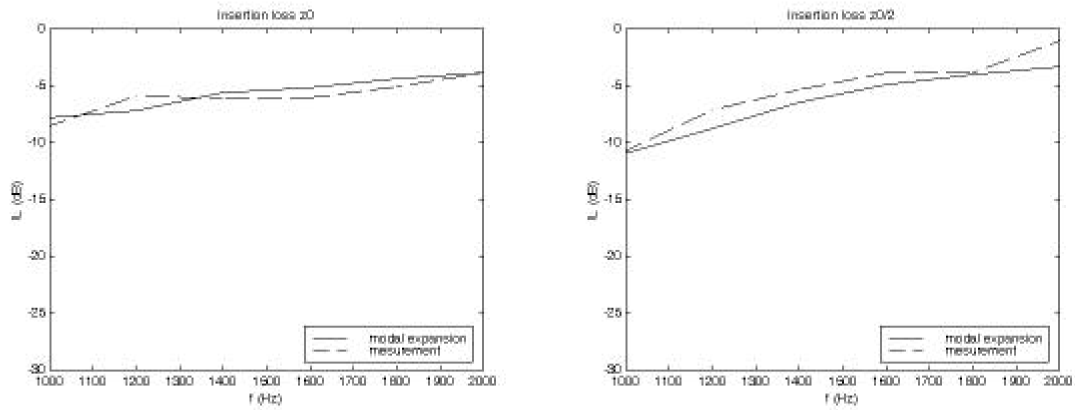


Figure 4: Comparison of predicted and measured values of the Insertion Loss

POROUS MATERIAL CHARACTERIZATION USING ACTIVE CONTROL

Open-cell porous materials are widely used as acoustic absorbent media for reducing the noise in the transport industry. The acoustic performances of such materials mainly depend on their intrinsic characteristics. Complex models including a large number of parameters have been developed to predict the acoustic behavior of porous media. For instance six parameters are used in the Lafarge-Allard's model [3], where the frame is considered motionless: resistivity, porosity, tortuosity, the viscous and thermal characteristic lengths and thermal permeability. A complete description of the acoustic behavior of a porous material requires therefore many parameters to be determined experimentally. Most of these parameters can be identified separately by means of a specific bench but a precise and rigorous determination of all the parameters is usually time consuming and requires many samples of different sizes. This last point becomes critical if the porous sheet is inhomogeneous. Moreover the parameters often have to be adjusted through acoustic measurements (absorption coefficient and surface impedance). We demonstrate in our study the possibility of globally identifying the parameters of a porous sample by using a unique set-up, the standing wave tube and active control. Three methods for identifying the six parameters were tested and compared on about ten different porous materials. The experimental set-up is the standing wave tube represented on figure 5. The basic principle is to apply different boundary conditions at the rear face of the porous sample and to measure the induced change in the front face impedance. Modeling the transfer through the layer allows to deduce the properties of the material. Asymptotic developments are used at low frequencies because they lead to a sequential determination of some parameters.

In this way, resistivity is firstly determined using the low frequency expression of the real part of the surface impedance with a soft impedance boundary condition behind the material. As previously seen, the surface impedance becomes equal to the flow resistance of the porous sample. The resistivity is then deduced knowing the sample thickness. This phase directly corresponds to the inverse process of designing an active absorber. The soft impedance at the rear face of the sample is experimentally achieved by active control over the range [50 Hz, 300 Hz].

The porosity is also identified by low frequency measurements of the surface admittance but with a rigid wall boundary condition. In this case, the imaginary part of admittance is proportional to frequency and porosity [4]. This determination requires a severe control of the ambient atmospheric conditions (temperature, pressure and humidity); a preliminary measurement of the surface impedance of the rear wall is also necessary to take into account the non perfectly reflecting boundary condition. The resistivity has to be predetermined in this case.

Tortuosity, characteristic lengths and thermal permeability are finally determined by theory-measurement adjustments. They can be realized on the absorption coefficient, the surface impedance or even on the effective density and the dynamic compressibility. In the last case these frequency dependant functions are measured by means of Utsuno's transfer function method [5].

The results obtained by each method are then compared using three other different boundary conditions at the rear face of the porous material. The adjustment on the effective density and the dynamic compressibility provides the best predictions on the absorption coefficient and the surface impedance (see figure 6) in most cases. This result has been confirmed by comparing the parameter values obtained from classical test benches, in the context of the IMPACT project. A very good agreement is observed, particularly on resistivity, porosity and tortuosity.

One of the main advantages of our identification method is its rapidity. Some measurements have shown that the dispersion can be very important within a material sheet. An average of several sample characteristics (and the interval of their variations) can be rapidly processed. Afterwards, these parameter ranges can be used as input in numerical simulation for predicting the material behavior in realistic applications, in a more reliable way.

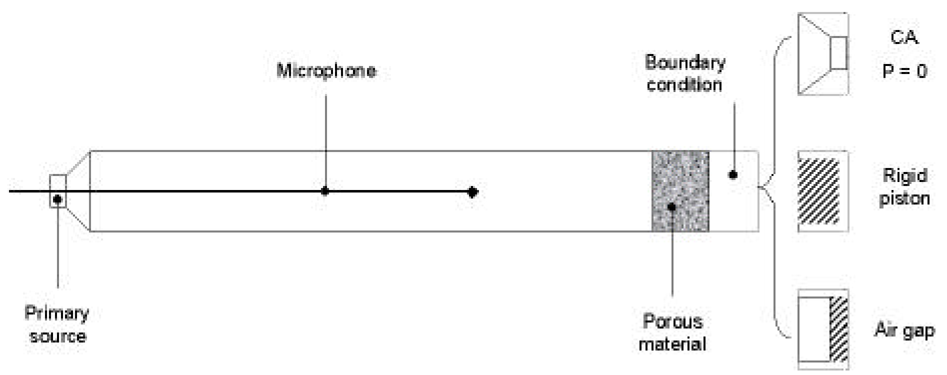
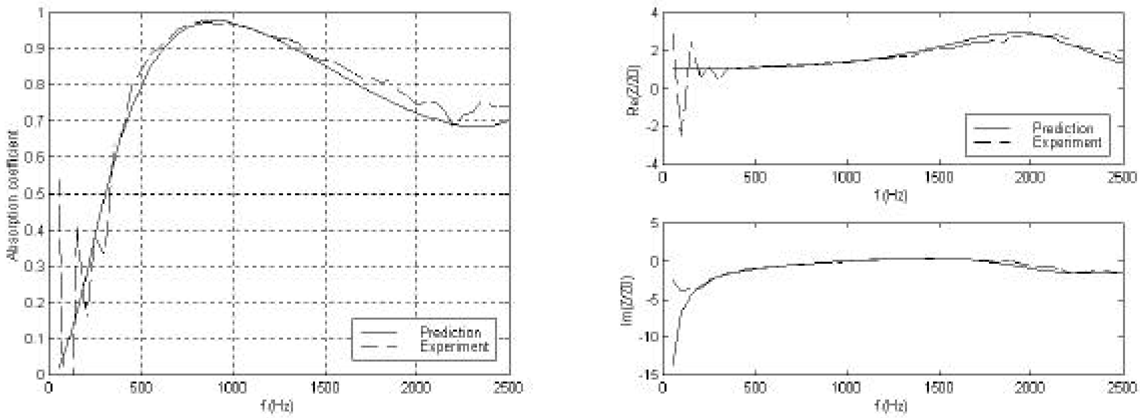


Figure 5 : Experimental set-up, the standing wave tube.



a) Absorption coefficient   b) Surface impedance

Figure 6 : Comparison between prediction and measurement for a 25 mm felt : air gap of 48 mm.

This study was supported in part by the EC in the context of the RANNTAC project (“Reduction of aircraft noise by nacelle treatment and active control", Brite Euram BE97-4121), by the French government in the context of the national program PREDIT 99A0530 and by the region Rhône-Alpes (IMPACT project).

References

[1] M. Furstoss, D. Thenail & M.A. Galland 1997, *Journal of Sound and Vibration, 203(2),* 219-236. Surface impedance control for sound absorption: direct and hybrid passive/active strategies.

[2] M.A. Galland, P. Souchotte, P. Ladner & T. Mazoyer 2001, *7th AIAA/CEAS Aeroacoustics Conference*, *Maastricht, The Netherlands, 28-30 May 2001, 2001-2221*. Experimental Investigation of Noise Reduction in a Flow Duct through Hybrid Passive/Active Liner.

[3] D. Lafarge, P. Lemarinier & J.F. Allard, 1997, Dynamic compressibility of air in porous structures at audible frequencies, *J. Acoust. Soc. Am.*, 102(4), 1995-2006.

[4] N. Sellen, M.A. Galland, O. Hilbrunner 2002, 8th *AIAA/CEAS Aeroacoustics Conference*, *Breckenridge, Colorado, 17-19 June 2002, 2002-2504*. Identification of the characteristic paramters of porous media using active control.

[5] H. Utsuno, T. Toshimitsu & F. Takeshi, 1989, Transfer function method for measuring characteristic impedance and propagation constant of porous materials, *J. Acoust. Soc. Am.*, 86(2), 637-643.