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Optimization of muffler transmission loss by using microperforated panels

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Abstract

The purpose of this work is to optimize the acoustic performance of low cost, simple geometry mufflers by using microperforated panels (MPP) in their expansion chambers. The Transmission Loss (TL) given by a computed model is compared with laboratory measurements, both for the mufflers containing the microperforated panels and without them. The optimization calculation is based on the easy computing transfer matrix approach. Then, the Boundary Element Method (BEM) is used in order to compare the evaluation of the TL. Different configurations have been tested so as to detect the real effect of resonator absorbers based on microperforated panels in the expansion chambers. It is shown that their presence increases the TL at certain frequencies if their parameters are well chosen, but their dissipative effect is negligible when occurs at a reactive effect resonance. Thus, the MPPs can be an alternative to improve the TL for low frequencies when the reactive effect of the mufflers decreases.

Resumen

El propósito de este trabajo es optimizar las prestaciones acústicas de silenciadores de geometrías simples y bajo costo mediante el empleo de paneles microperforados (MPP) en el interior de sus cámaras de expansión. Esta investigación compara el índice de pérdidas de transmisión (TL) brindadas por un modelo computacional con las mediciones realizadas en laboratorio, tanto para un silenciador que contiene los resonadores microperforados como para otro sin éstos. El cálculo de la optimización se realizó en base a una aproximación simple del Método de Matriz de Transferencia. Luego se utilizó el Método de Elementos de Contorno (BEM) para comparar la evaluación del TL. Se probaron diferentes configuraciones con el objetivo de detectar el efecto real de los absortores resonadores basados en paneles microperforados dentro de sus cámaras de expansión. Se observa que la presencia de los MPP incrementa el TL en ciertas frecuencias si sus parámetros son bien elegidos, pero su efecto disipativo es mínimo cuando tienen lugar resonancias de efecto reactivo.

Por lo tanto, los MPP pueden ser una alternativa para mejorar el TL en bajas frecuencias cuando el efecto reactivo de los silenciadores disminuye.

1 Introduction

Nowadays, passive mufflers are widely employed to reduce industrial and domestic noise and are a key tool for acoustic comfort control. Their basic geometry, formed by a simple expansion chamber, shows weaknesses in its acoustic performance parameter called Transmission Loss (TL). This effect is commonly limited by using complex geometries or by adding porous materials inside the chamber. However, when a clean absorbent system is desirable or when the muffler must support high air flux, it is not possible to add those fibrous materials. The aim of this work is to discuss the use of microperforated panels (MPP) as another alternative to improve the acoustic performance of a muffler.

The fundamental design of MPPs was developed by Maa in the seventies and is currently used for the acoustic conditioning of rooms. Nevertheless, in industry, this application is still in development. The model considers a microperforated sheet characterized by its acoustic impedance. When the acoustic wave spreads across the perforations, whose dimensions are of the order of magnitude of the thermal and viscous boundary layers, a part of the acoustic energy is transformed by friction and heat exchange. Coupled with a rigid wall by an air space, such a system is similar to an improved Helmholtz resonator. To obtain an absorbing system with a larger frequency range than a classical Helmholtz resonator, the perforation diameter must be sub-millimetric. It leads to a system more efficient in situations of high mechanical or thermal strain, in comparison to flexible porous material.

In this paper, the effect of this absorber is optimized in order to maximize sound absorption for frequencies with a small TL by a program based on the transfer matrix method. The plane wave analytical prediction is then compared with BEM results and with laboratory measurements to show the effect of the MPP on the expansion chamber.

2 Effect of the MPP on an extended inlet muffler

2.1 Mufflers Transmission Loss (TL)

There are several parameters to describe the acoustic attenuation performance of an expansion chamber. These include the Noise Reduction (NR), the Insertion Loss (IL) and the Transmission Loss (TL). Among these acoustic parameters, the TL is the only one that can be easily calculated and measured according to the main aim of this paper. It is defined as the difference in the sound power level between the incident wave exciting the mufflers *Wi* and the transmitted wave *Wt* to an anechoic termination.

$$TL = 10\log_{10}\frac{Wi}{Wt}. \tag{1}$$

In practice, an anechoic termination is difficult to obtain, particularly for the low frequencies. However, the measurement can be improved by using the Two-Load Method described by Tao and Seybert. This method is based on the transfer matrix approach that will be described later.

Figures 1 and 2 illustrate the muffler that has been used for the simulations and the measurements. It is composed of a simple expansion chamber with two characteristics on both sides of the muffler: extended inlet and outlet including the MPP.

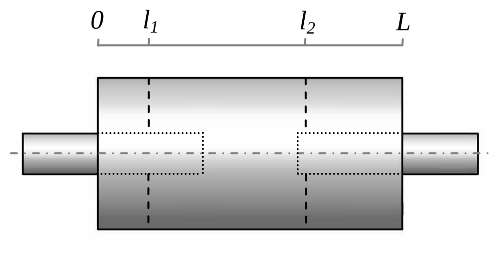


Figure 1. Muffler with extended inlet/outlet and MPP

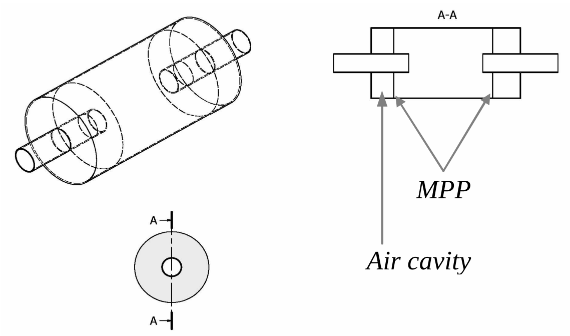


Figure 2. Muffler drafting

2.2 The microperforated panel (MPP) as a sound absorber

A microperforated panel can be seen as a short narrow tube distribution with small diameters compared to the wavelength of the incident sound wave.

Maa introduced an approximation formula for the sound absorber defined by the association of the MPP and an air cavity. The MPP can be defined by specific impedance, normalized by $\rho_o c$ the air characteristic acoustic impedance and σ the panel porosity

$$z_{mpp} = r + j\omega m\,, \tag{2}$$

where

$$r = \frac{32\mu}{\rho_o \sigma c}\frac{e}{d^2}\left[\sqrt{1+\frac{x^2}{32}}+\frac{\sqrt{2}}{8}x\frac{d}{e}\right], \tag{3}$$

$$\omega m = \omega\frac{e}{\sigma c}\left[1+\frac{1}{\sqrt{3^2+x^2/2}}+0{,}85\frac{d}{e}\right], \tag{4}$$

with r and m respectively the acoustic resistance and the acoustic reactance, μ the viscosity coefficient of the air, ρ_o the density of the air, c the sound speed in air, ω the angular frequency, d the orifice diameter and e the thickness of the panel.

In the equations (3) and (4) $x = d\sqrt{\frac{\rho_o \omega}{4\mu}}$ is the perforation constant defined as the ratio of the orifice diameter to the viscous boundary layer thickness of the air in the orifice.

A microperforated panel placed in front of a solid surface, with an air cavity of thickness L between them, makes an MPP absorber. The acoustic impedance of the cavity is

$$z_c = -j\cot\left(\frac{\omega}{c}L\right). \tag{5}$$

The acoustic impedance of the absorber is given by

$$z = z_{mpp} + z_c \,. \tag{6}$$

Finally, the sound absorption coefficient α is calculated using the well-know equation

$$\alpha = 1 - \left| \frac{z-1}{z+1} \right|^2 . \tag{7}$$

According to Maa, the model is useful while the perforate constant is above 1 and below 10. This is equal to require that the perforation diameter d must be in the order of magnitude of the thermal and viscous boundary layers. This leads to a sub-millimetric diameter in the expecting frequency range.

2.3 TL optimization

The Transmission Loss of the mufflers is calculated by using the Transfer Matrix Method described by Munjal. This method discretizes a muffler geometry into elements that can take the flow into account. For each element, the pressure p and the velocity v at two points can be linked by a matrix

$$\begin{bmatrix} p_i \\ v_i \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} p_{i+1} \\ v_{i+1} \end{bmatrix}, \tag{8}$$

where A, B, C and D are usually called the four-pole constants embodying the acoustic properties of a pipe. Using the plane wave hypothesis those parameters can be written as

$$A = e^{-jMk_c h} \cos(k_c h) \,, \tag{9}$$

$$B = j \frac{\rho_o c}{S} e^{-jMk_c h} \sin(k_c h), \tag{10}$$

$$C = j \frac{S}{\rho_o c} e^{-jMk_c h} \sin(k_c h), \tag{11}$$

$$D = e^{-jMk_c h} \cos(k_c h) \,. \tag{12}$$

where $M = V / c$ is the mean flow Mach number (M<0,2), V is the mean flow velocity, $k_c = k / (1 - M^2)$ is the convective wavenumber, $k = \omega / c$ is the acoustic wavenumber, S is the constant cross section of the element and h its length.

Therefore, from the matrix of each element, the assemblage stiffness matrix is calculated and leads to knowledge of the system response. Due to the plane wave hypothesis this method is limited because it can be used only up to the cut-off frequency of the muffler, but it is easy to compute.

A program calculates the TL of a muffler and looks for its first minimum. For the associated frequency, an optimization subroutine, based on the Nelder-Mead method, searches for suitable parameters of the MPP sound absorber that could increase the TL around this frequency. As seen before, there are four parameters describing the absorber behavior: σ the panel porosity, d the orifice diameter, e the panel thickness and L the air cavity thickness. For industrial application, it is not necessary to make an optimization based on the four parameters, because it would not be possible to manufacture panels with different attributes for each muffler. Consequently, the optimization is only based on the thickness of the air cavity.

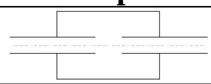
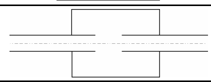
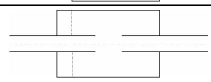
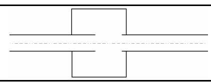
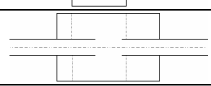
With this configuration including an MPP, the TL is evaluated considering the MPP by its acoustic impedance and the program looks for the frequency of the new first minimum. Then, the optimization subroutine calculates the other air cavity thickness.

3 Experimental verification

In order to compare the effect of microperforated panels in an expansion chamber, different configurations of a muffler with inlet and outlet extensions have been tested (see Table 1). The TL has been first measured without panels or sheets in the expansion chamber of length L (see Figure 1). Then, microperforated panels or rigid sheet have been successively introduced at the positions l_1 and l_2 calculated by the optimization program.

The MPP used for the measurements is an industrial sample from the Swedish company Sontech whose effect has already been proved as an interesting sound-absorbing material like in the Dupont's thesis work.

Table 1. Configurations tested

Configuration	l_1	l_2	Description
#1	-	-	
#2	*Rigid Sheet*	-	
#3	*MPP*	-	
#4	*Rigid Sheet*	*Rigid Sheet*	
#5	*MPP*	*MPP*	

The transfer matrix method can just be used up to the muffler cut-off frequency corresponding to the limit of the plane wave hypothesis. For a better comparison between theoretical approach and measurements, a calculation based on the Boundary Element Method (BEM) is made in order to evaluate the TL above this frequency. This one is based on the investigation work of Pasqual and Arruda.

Thus, the transfer matrix method gives a rapid result to evaluate the sound absorber air cavity. The TL is then evaluated over a wide frequency range from the BEM.

Measurements have been carried out according to the Two-Load Method described by Tao and Seybert, as shown in Figure 3. In equation (8) it can be seen that there are four unknowns but there are only two equations. The method consists in measuring the sound pressure at four points of the system by changing the end conditions between two measurements to obtain the four parameters of the transfer matrix approach. This has been achieved by changing the impedance at the termination from Z_1 to Z_2, with and without absorbing materials.

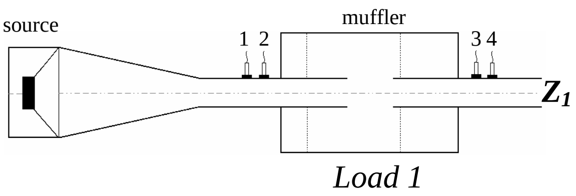


Figure 3. Experimental set up

4 Results and discussion

4.1 Comparison without MPP

Figure 4 presents the TL obtained by the plane wave analytical approximation, the BEM calculation and experimental measurements for the inlet and outlet extended muffler of the Configuration #1 (see Table 1). It shows that below the expansion chamber cut-off frequency the two simulation approaches are relatively similar. As it was expected, the transfer matrix method does not provide satisfying results above this frequency. For this reason, the next figures will be just presented with the BEM results when the muffler does not have MPPs. The effect of microperforated panels is expected for low frequencies in order to improve the small TL values. This shows that the analytical approach is sufficient to do the work of optimization that consists in finding the minimums of the TL below the cut-off frequency.

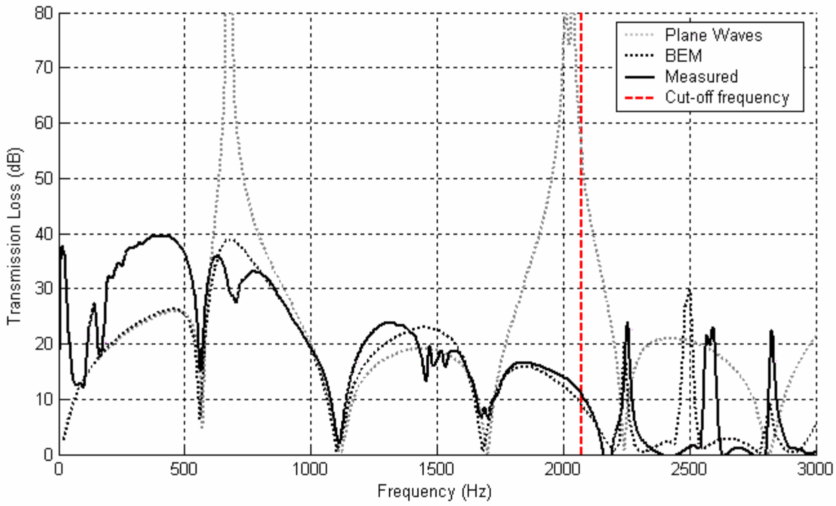


Figure 4. TL comparison for Configuration #1 : Plane Waves Method, BEM, measured

Considering the BEM result and the measurements, it can be noticed that the two results are relatively equals. The visible difference below 500 Hz could be due to a structural damping of the sound wave ignored by the BEM.

4.2 Comparison with one MPP

Figure 5 shows the TL of the reactive muffler of the Configuration #2 (see Table 1). In comparison with the TL of the Configuration #1 (Figure 4), the muffler's geometry change leads to a cancellation of the second minimum between 1000 Hz and 2000 Hz. Keeping this geometry, Figure 6 shows a muffler where the rigid sheet has been replaced by a MPP with its air cavity at position l_1 (see Figure 1). By comparing measurements of Figures 5 and 6, it can be remarked the effect of the MPP in the expansion chamber. It shows that the MPP leads to a TL improvement of the minimums.

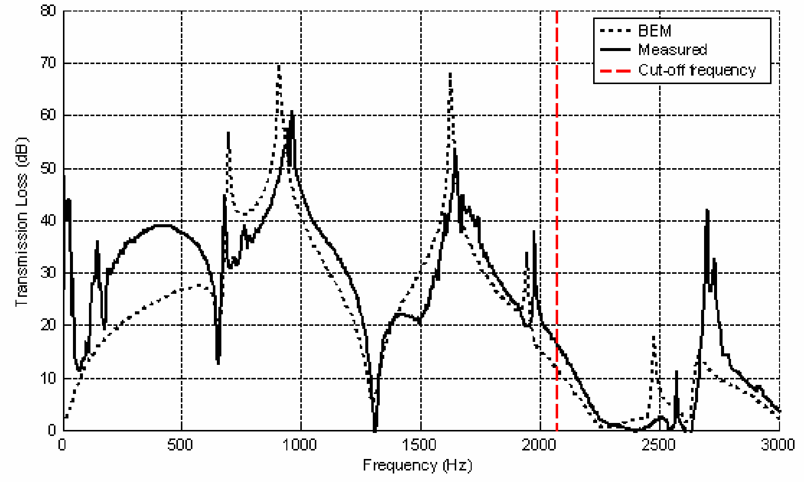


Figure 5. TL comparison for Configuration #2 : BEM, measured

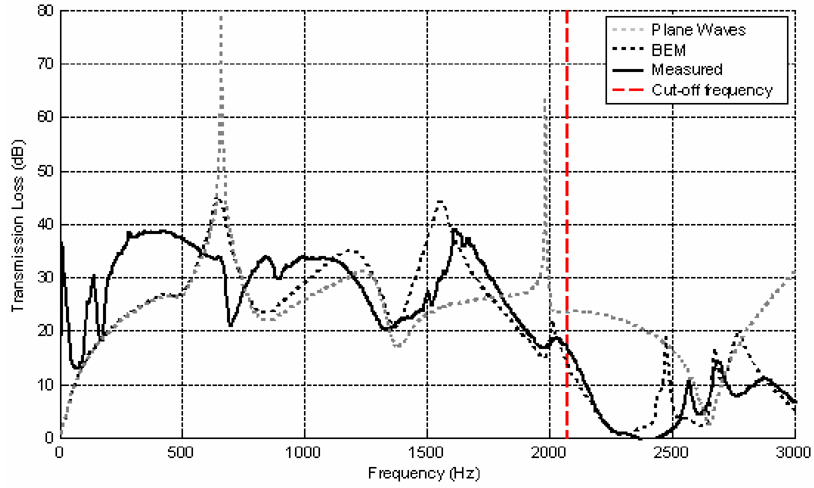


Figure 6. TL comparison for Configuration #3 : Plane Waves Method, BEM, measured

It can be also noticed from the measurements that the maximums of absorption due to the reactive effect resonances are reduced. This can be easily explained by the fact that it occurs when the sound wave is completely reflected inside the expansion chamber. The presence of an absorbing material, like an MPP, limits these reflections and, thus, limits the sound attenuation.

The depth of the air cavity has been calculated by the optimization program to have an effect on the first minimum of the TL obtained with the Configuration #1. As said before, the MPP is considered in the computational model by its acoustic impedance. The two simulations in Figure 6 show that its influence improves largely the TL for the desired frequencies. The experimental measurement does not show very well this effect. It may be due to an overestimation of the MPP's effect in the models or to the behavior of this particular microperforated panel that is not well known up to now.

4.3 Comparison with two MPP

In Figures 7 and 8 is depicted the comparison between measurements and simulations respectively for the Configurations #4 and #5 (see Table 1). For the Configuration #5, a second air cavity depth has been calculated by the optimization program to have a positive effect on the new first minimum of the TL obtained earlier with Configuration #3. Configuration #4 is Configuration #5 but replacing MPPs by rigid sheets.

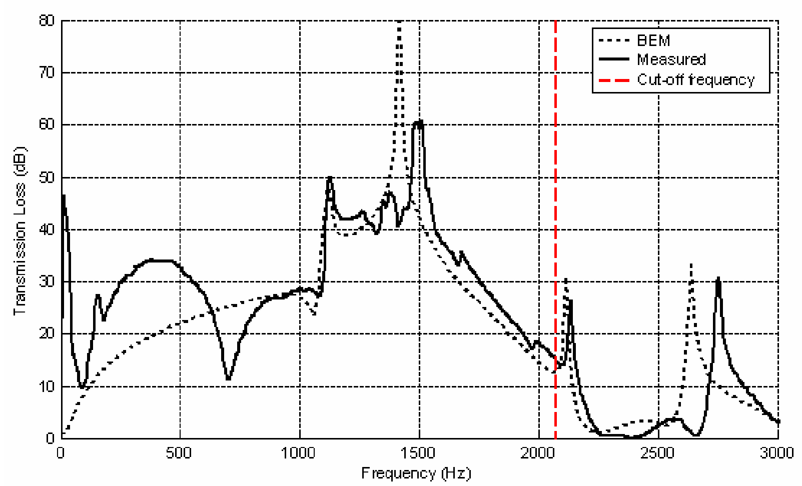


Figure 7. TL comparison for Configuration #4 : BEM, measured

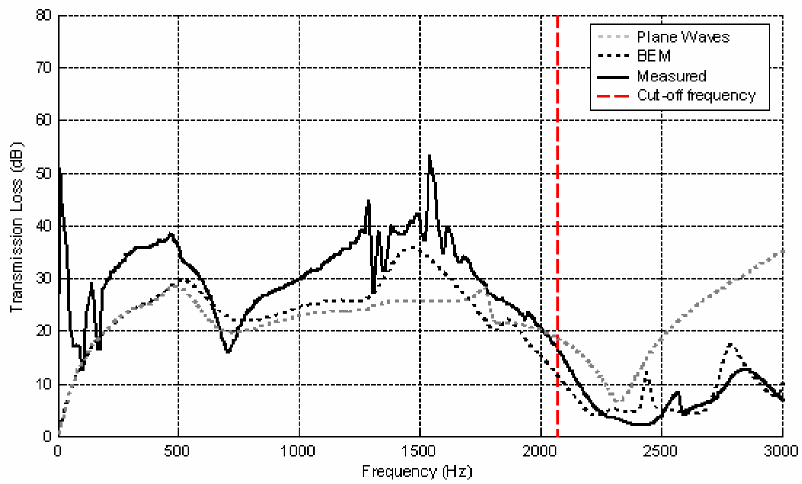


Figure 8. TL comparison for Configuration #5 : Plane Waves Method, BEM, measured

It is a fact that geometry modifications involve very different results. In this case, it is beneficial to the muffler's reactive effect. A similar analysis concerning the influence of the MPPs can be carried out from these results : the panels improve lightly the muffler acoustic performance for low frequencies and reduce the sound absorption at reactive effect resonances, making this way the TL curve smoother.

The experimental measurements do not lead to same results than numerical calculations. Once again, it can be due to the microperforated panel behavior that is not well known or to the simulations that are too much simplifying regarding the MPP's behavior in the mufflers.

5 Conclusion

The acoustic behavior of microperforated panels inside an extended inlet and outlet muffler has been investigated in detail in this work. Measurements have been compared with simulations based on an analytical approach and on the Boundary Element Method. It is shown that the MPPs can improve the TL of an extended inlet and outlet muffler at low frequencies when a traditional fibrous absorbing material could not. The model used for the optimization calculations has been validated by the BEM simulations as long as it is used below the cut-off frequency of the expansion chamber. Nevertheless, the work shows that the reactive effect produced by the mufflers geometry is much more important than the dissipative effect provided by the MPP.

To conclude, the microperforated panels can be used as another alternative to improve the acoustic performance of a muffler if their effect do not occur at a reactive effect resonance.

Referencias

Maa, D. Y. (1998). “Potential of Microperforated Panel Absorber”. Journal of Acoustical Society of America, Vol. 104, No. 5, pp. 2861-2866.

Tao, Z.; Seybert, A.F. (2003). “A review of Current Techniques for Measuring Muffler Transmission Loss”. Society of Automotive Engineers, inc, 03NVC-38.

Munjal, M. L. (1987). “Acoustics of Ducts and Mufflers – with Application to Exhaust and Ventilation System Design”. Ed. John Wiley & Sons, New York.

Nelder, J.A.; Mead, R. (1964). “A simplex method for function minimization”. The Computer Journal, No. 7, pp 308-313.

Dupont, T. (2002): “Transparence et absorption acoustiques des structures microperforées”. Thesis, Institut National des Sciences Appliquées de Lyon.

Pasqual, A.M.; Arruda J.R. (2007). “Improving the acoustic performance of expansion chambers by using microperforated panels absorbers”. COBEM 2007, 19th International Congress of Mechanical Engineering.

Denia, F.D.; Selamet A. (2007). “Acoustic attenuation performance of perforated dissipative mufflers with empty inlet/outlet extensions. Journal of Sound and Vibration, No. 302, pp 1000-1017.

Wu, T.U., Zhang, P. and Cheng, C.Y.R. (1998), “Boundary Element Analysis of Mufflers with an Improved Method for Deriving the Four-Pole Parameters”. Journal of Sound and Vibration, Vol.217, No. 4, pp. 767-779.