ANALYSIS OF DISCHARGE MUFFLER DESIGNS FOR GAS PULSATION ATTENUATION IN RECIPROCAL COMPRESSORS

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Abstract. *Gas pulsation is one of the major contributors regarding noise generation in household refrigerators. The compressor discharge chamber generates gas pulsation thereafter the condenser transfers these pulsations to the cabinet. The cabinet is directly connected to the back of the refrigerator. This work proposes the use of analytical and numerical methods to explore different designs for a specific compressor discharge muffler, in order to obtain maximum attenuation of the noise generated. Traditional methods for noise control were applied in this work, such as insertion of expansion chambers and application of porous materials. This material was modelled by the Johnson-Lafarge's approach as an equivalent fluid. Physical parameters characterize the equivalent fluid, i.e. the complex sound velocity and the complex density. Transmission loss was used to evaluate the acoustics performance of the proposed designs.*

Keywords: *compressor, porous material, acoustics*

1. INTRODUCTION

Gas pulsations is a fundamental process in working compressors. Unfortunately, it increases the effect of noise generation. Each component of the compressor, e.g. housing, discharge and suction tubes, mufflers (discharge and suction), could be a path of energy transfer. A study regarding reciprocal compressor by Bratti *et al.* (2012) quantified noise transfer along these paths. This research concluded that discharge mufflers are capable of decreasing the sound power level, especially for low frequencies.

The use of porous material in the chamber of the discharge muffler is an effective method for the attenuation of noise and the control the performance of compressor (Soedel, 2006). Different researches (Wang *et al.*, 2009; Yoon, 2013) increased the acoustics performance of the discharge, consequently decreased the sound power level of the compressor with this method. Mareze (2009) noted that acoustics properties of the porous material like airflow resistivity, porosity and tortuosity are highly important input data of the models.

The objective of this research is to analyse the influence of porous material in prototype mufflers. A numerical model based on FEM (Finite Element Method) of the silencer was constructed in LMS Virtual.Lab to enable accurate solutions of the acoustic performance. With the secondary benefit of avoiding manufacturing many different prototypes.

2. LITERATURE

Munjal (1987) defined the acoustic performance of mufflers, including the transmission loss parameter and others terms. The physical meaning of the transmission loss is defined as the ratio between the incident power level and the transmitted power level. Jacobsen and Juhl (2013) analytically determined the transmission loss for a simple muffler considering only plane waves, shown in Eq. (1)

$$TL = 10log\left(1+\frac{1}{4}\left(h-\frac{1}{h}\right)^2 sin^2kl\right), \tag{1}$$

where h is the ratio of the cross-sectional areas and l is the length of the chamber. This derivation assumed that the end is an anechoic termination. Note that the transmission loss is zero when l is a multiple of half wavelength.

After obtaining the acoustic parameter to evaluate the muffler system, it is possible to use analytical models for representation of the porous material. Zwikker and Kosten (1949) used the wave propagation model for rigid porous material to represent it like an equivalent fluid. In other words the porous medium is considered a fluid. Lafarge *et al.* (1997) used this hypothesis and defined the inertial and viscous effects of porous material on fluid, according to Eq. (2), e.g. the effective dynamic density. While Eq. (3) represents the interaction between fluid and structure of porous material, e.g. the effective bulk modulus. These equations are valid for Johnson-Lafarge's model

$$\tilde{\rho}_{ef}(\omega) = \rho_o \alpha_\infty \left(1 + \frac{\phi\mu}{\mathrm{i}\omega\rho_o\alpha_\infty q_o}\left(1 + \frac{4\omega\rho_o q_o^2\alpha_\infty^2}{\mu\phi^2\Lambda^2}\right)^{1/2}\right), \tag{2}$$

$$\tilde{K}_{ef}(\omega) = \frac{\gamma P_o}{\gamma - (\gamma - 1)\left(1 + \frac{\phi\mu}{\mathrm{i}\omega\rho_o Pr q'_o}\left(1 + \frac{\mathrm{i}4\omega\rho_o Pr q'^2_o}{\mu\phi^2\Lambda'^2}\right)^{1/2}\right)^{-1}}. \tag{3}$$

The microscopic parameters of the porous material are: ϕ is the porosity, α_∞ is the tortuosity, Λ is the viscous characteristic length, Λ' is the thermal characteristic length, q_o is the static viscous permeability and q'_o is the thermal viscous permeability. Thermal properties of the fluid are: γ is the ratio specific heat, μ is the dynamic viscosity, Pr is the Prandtl number, ρ_o is the density, P_o is the static pressure. The equivalent fluid model allows to obtain the input data parameters for models of porous material, such as complex density and complex sound velocity. Hence, the Equation (4) allows to calculate the complex sound velocity as function of the before mentioned definitions,

$$\tilde{c}(\omega) = \left(\frac{\tilde{K}_{ef}(\omega)}{\tilde{\rho}_{ef}(\omega)}\right)^{1/2}. \tag{4}$$

In this context, the absorption coefficient is another acoustic parameter of the porous material that identifies the optimal frequency range in maximum absorption. For instance, the Johnson-Lafarge's model could predict the absorption coefficient of the porous medium. Figure 1 shows an example of the absorption coefficient for a typical porous material, which is often used in discharge mufflers.

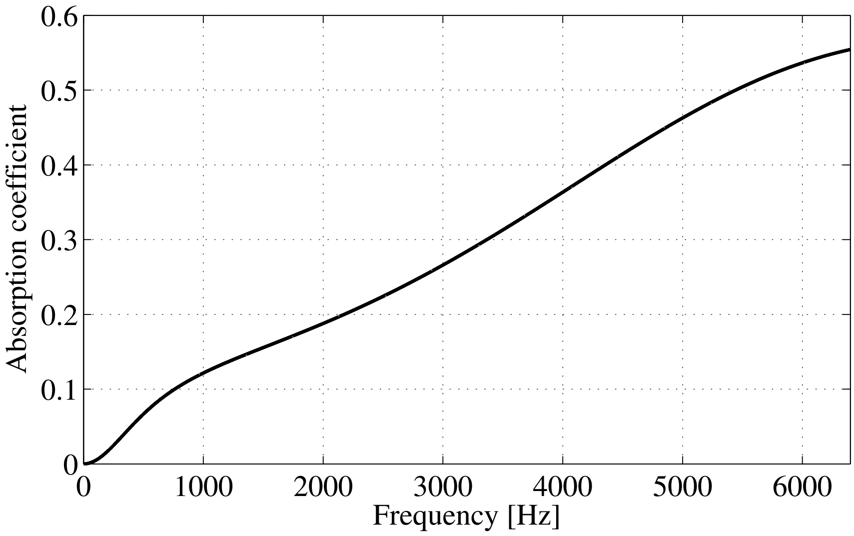

Figure 1. Absorption coefficient of porous material.

3. NUMERICAL ANALYSIS

A three points method to obtain the transmission loss in numerical analysis was shown by Bilawchuk and Fyfe (2003). This method makes use of the acoustics pressure at three points, as depicted in Fig. 2. It is important to emphasize that the pressures are analysed at a face (group of nodes), instead of a point, because the model presents three dimensions.

The pressures P_1 and P_2 are written as function of the incident (P_i) and the reflected pressure (P_r), respectively, as is shown in Eq. (5) and Eq. (6),

$$P_1 = P_i e^{\mathrm{i}kx_1} + P_r e^{-\mathrm{i}kx_2}, \tag{5}$$

$$P_2 = P_i e^{\mathrm{i}kx_1} + P_r e^{-\mathrm{i}kx_2}. \tag{6}$$

Furthermore, it is possible to write the incident pressure as a function of P_1 and P_2, according to Eq. (7),

$$P_i = -\frac{1}{2\mathrm{i}\sin k(x_2 - x_1)}\left[P_1 e^{-\mathrm{i}kx_2} - P_2 e^{-\mathrm{i}kx_1}\right], \tag{7}$$

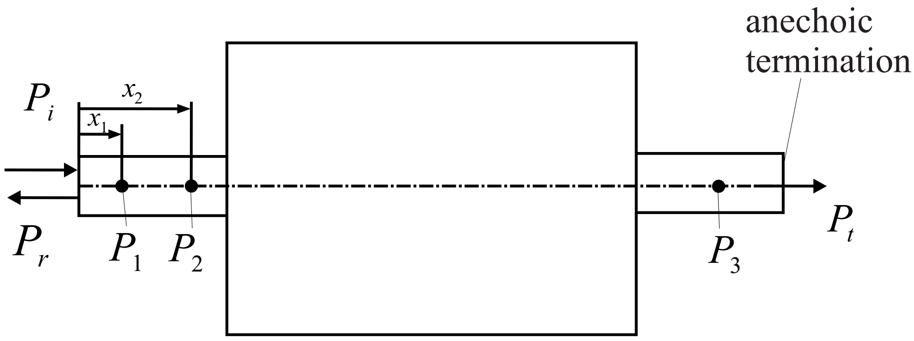

Figure 2. Three points method.

where, $\sin k(x_2 - x_1) \neq 0$ or $k(x_2 - x_1) \neq n\pi, n = 0, 1, 2, ...,$ etc. The positions x_1 and x_2 are calculated according to the frequency range analysed (Bodén and Åbom, 1986). Then, in this case the transmission loss can be written as Eq. (8)

$$TL = 20log\left(\frac{|P_i|}{|P_t|}\right) + 10log\left(\frac{S_i}{S_o}\right), \tag{8}$$

where S_i is the inlet cross-sectional area and S_o is the outlet cross-section area.

4. RESULTS AND DISCUSSION

In order to confirm the quality of the numerical model it was made an analytical solution was compared with the numerical solution. The values corresponding to the analytical curve are l = 60,7 mm and h = 53,08. The mesh used in this analysis present 31254 hexahedral acoustics elements which has 44998 nodes. Air at 20 ^{o}C was considered as working fluid. The curves of the Transmission Loss are depicted in Fig. 3. The curves show shows good agreement for the frequency range 500 to 5 kHz. Besides, the first dip is due to longitudinal resonances.

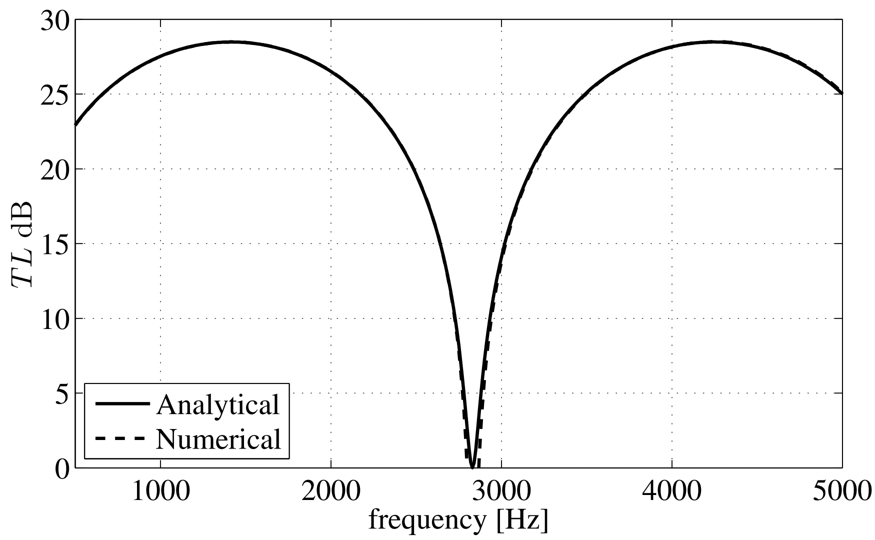

Figure 3. Initial validation: analytical and numerical.

The next analysis was dedicated to add porous material in the chamber of the muffler, in the numerical model. The porous material properties are: ϕ = 0,84, σ = 4715 Rayl/m, α_∞ = 1,09, Λ = 194,6 μm and Λ' = 247,9 μm (Mareze, 2013). In fact the analytical model can feed the numerical model with the complex density and complex sound velocity. Figure 4 (a) shows four models where each layer has thickness of 5,5 mm. During these analyses the same fluid as during validation considered.

Figure 4 (b) shows the effect of porous material in the chamber of the muffler. As can be seen the more layer increased is the TL, especially for low and high frequency range, because decrease transmitted pressure level. This may be because the sound velocity in porous material decrease while air flows through it. Also all the curves are smoothed between 2 and 3 kHz.

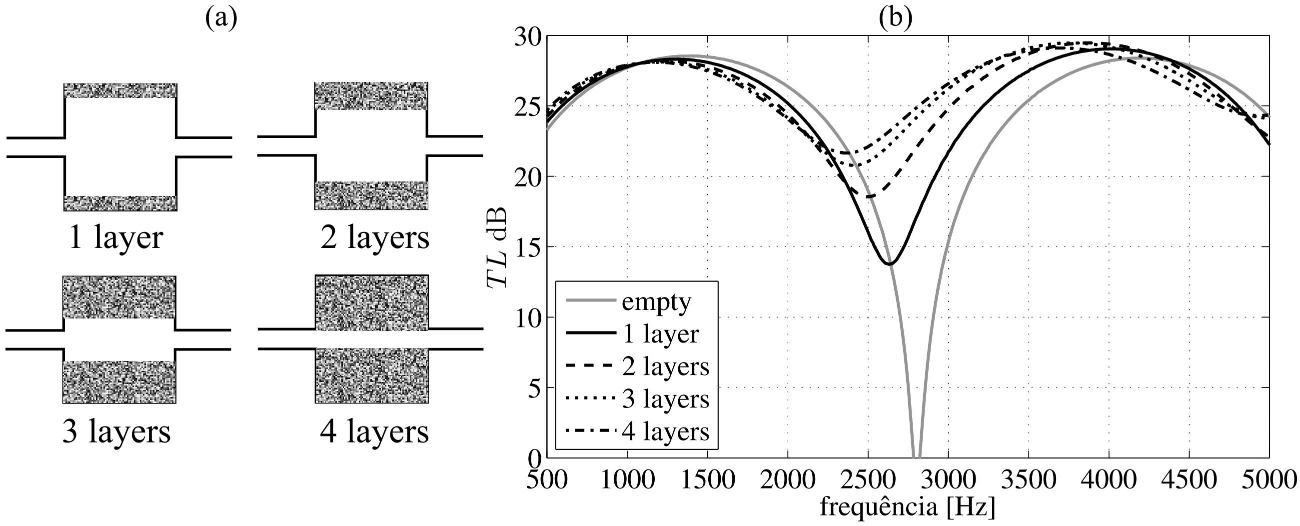

Figure 4. Influence of layers porous material: (a) position of material and (b) transmission loss.

The last analysis adds a transversal barrier with a hole in the muffler chamber, as depicted in Fig. 5 (a). Two models are visualized whereas each model is analysed with an empty chamber and filled with porous material. In model 1 the position of barrier is near the outlet, while in model 2 it is in the middle. The same material properties as previous sections were used.

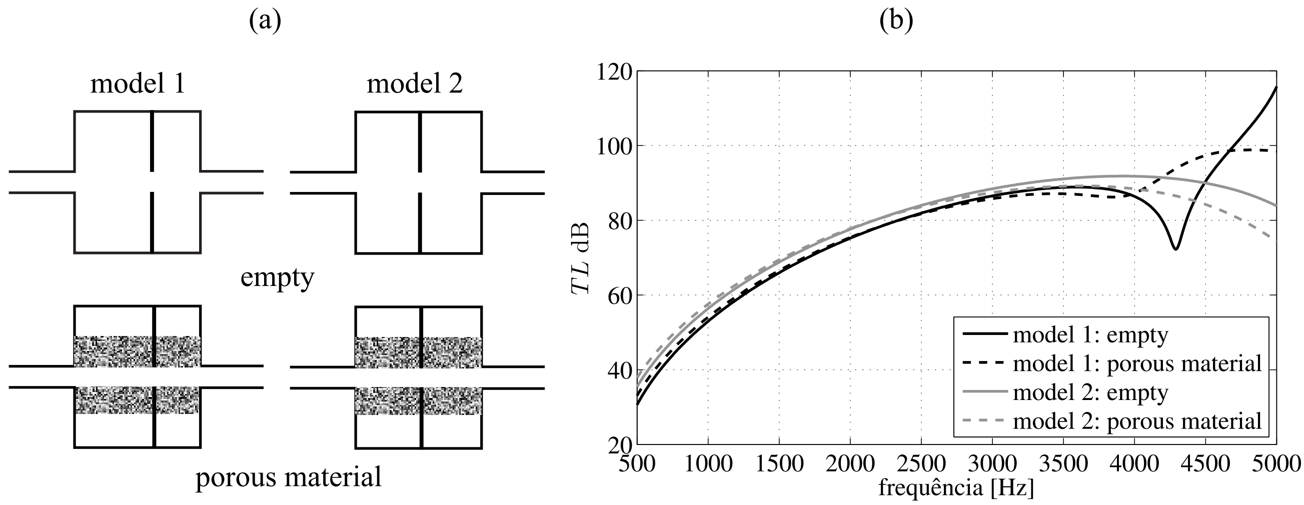

Figure 5. Sensitivity analysis: (a) position of material and (b) transmission loss.

Figure 5 (b) shows the results of the analyses, that high increase the attenuation curves if compared to the model with no barrier. The difference between the analysed models is about 2 dB. Additional barrier reduces the transmitted pressure which increases the TL. In fact, in both models the additional porous material only change the attenuation in high frequencies.

5. CONCLUSIONS

The initial validation confirmed good accuracy of the numerical models. Good agreement between analytical and numerical results was obtained. Although the fluid is not works in reciprocal compressor (R134a or R600), therefore the methodology used was successful validated. The numerical models based on FEM which had been proposed for the acoustics analysis is an efficient tool, hence it will be used further analysis. Also analytical models using the Johnson-Lafarge are appropriate for representing porous mediums.

In muffler prototypes with absorbing material the dip is still present, although for a specific frequency range it shows better attenuation. In this context, the main idea of using porous material for discharge mufflers of reciprocal compressors is improving attenuation for some range frequency.

The proposed study is only the beginning the main author PhD thesis. Many others prototype designs will be explored through an optimization tool and implementation code with MatLab. In fact the first step was overtaken by development of the project.

6. ACKNOWLEDGEMENTS

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