

2008

Investigating the Transmission Loss of Compressor Suction Mufflers Applying Experimental and Numerical Methods

Israel Jorge Cardenas Nuñez
Tecumseh of Brasil Ltda

Ana Lucia Libardi De Marqui
Tecumseh of Brasil Ltda

Marcelo Cavaglieri
Tecumseh of Brasil Ltda

Jose Roberto de Franca Arruda
State University of Campinas of UNICAMP

Follow this and additional works at: <https://docs.lib.purdue.edu/icec>

Nuñez, Israel Jorge Cardenas; De Marqui, Ana Lucia Libardi; Cavaglieri, Marcelo; and Arruda, Jose Roberto de Franca, "Investigating the Transmission Loss of Compressor Suction Mufflers Applying Experimental and Numerical Methods" (2008). *International Compressor Engineering Conference*. Paper 1900.
<https://docs.lib.purdue.edu/icec/1900>

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information.

Complete proceedings may be acquired in print and on CD-ROM directly from the Ray W. Herrick Laboratories at <https://engineering.purdue.edu/Herrick/Events/orderlit.html>

Investigating the Transmission Loss of Compressor Suction Mufflers Applying Experimental and Numerical Methods

Israel Jorge Cárdenas Nuñez^{1*}, Ana Lúcia Libardi De Marqui¹, Marcelo Cavaglieri¹
José Roberto de França Arruda²

¹Tecumseh do Brasil Ltda. – Compressor Research & Development Group,
São Carlos, SP, Brasil
israel.nunez@tecumseh.com, ana.libardi@tecumseh.com, marcelo.cavaglieri@tecumseh.com

²Universidade Estadual de Campinas, Departamento de Mecânica Computacional,
Campinas, SP, Brasil
arruda@fem.unicamp.br

ABSTRACT

This paper investigates the Transmission Loss (TL) of compressor suction mufflers. The small diameters of the inlet and outlet tubes cause practical problems for the experimental measurement of the TL. A numerical analysis of the TL is performed to predict the muffler efficiency. The literature presents different techniques to obtain the transmission loss experimentally, such as the decomposition method, the two-source method, the two-load method and the transfer matrix method. The aim of this work is to present a numerical and experimental investigation of the transmission loss of a simple expansion chamber and a compressor muffler. Numerical results obtained using the Finite Element Method (FEM) are compared with experimental results. The experimental apparatus consists of a sound source and four microphone probes that are used due to the small diameters of the inlet and outlet tubes of the compressor muffler. Both numerical and experimental results present inaccuracies due to the limitations of the numerical model and the experimental set-up. The combined analysis shows the validity and the limitations of both numerical and experimental methodologies.

1. INTRODUCTION

Mufflers are used in a large variety of applications, and one of these is in hermetic compressors for domestic and commercial refrigeration. The muffler design must have high performance in order to minimize the noise in household refrigerators and freezers, which are the most popular appliances. The muffler working principle is based on wave reflection of incident acoustic energy back to the source. This reflection happens when waves meet severe impedance variation, independently if it increases or decreases. Changing the expansion chambers and ducts diameters at every junction an impedance mismatch is produced. So, a short quantity of energy passes through the muffler and most of the energy is reflected back to the source, Gerges (2000).

The complex design process of an acoustic muffler led, during many years, to the development of analytical, numerical and experimental techniques, which help the compressor designer to understand and develop new muffler geometries. Nowadays, mufflers with complex geometries are evaluated using numerical techniques based on the finite element method (FEM) and the boundary element method (BEM). In order to evaluate the performance of a muffler, Munjal (1987) detailed the theory of insertion loss (IL), transmission loss (TL) and noise reduction (NR), which can be used as acoustic performance parameters. In this paper, to evaluate the mufflers the transmission loss is used because this methodology is independent of the sound source that makes the design task easier.

There are many experimental ways to obtain the sound transmission loss; we can cite the *decomposition method*, *two-load method*, *two-source method* and, finally, the *transfer matrix method*, Tao (2001).

The aim of this paper is to show a numerical and experimental study to obtain the sound transmission loss from a simple expansion chamber and a muffler with small dimensions. The numerical analyses were performed using FEM (Finite Element Method) and the model validation was done with experimental results obtained using the *two-load method*. Due to the small dimensions of the inlet and outlet pipes, probes for commercial ½" microphones were developed.

The paper is organized in the following way: on section 2 the Transmission Loss (TL) basic concepts and different measurement techniques are presented; on section 3 the microphone probe project is described, on section 4 the numerical and experimental results for a simple muffler (one expansion chamber) are shown and, finally, on section 5 the paper conclusions are summarized.

2. MUFFLER TRANSMISSION LOSS

The muffler TL is the acoustical power level quotient between the power incident on the muffler and the power transmitted downstream assuming an anechoic termination. In the next section some TL measurement techniques used in the literature are presented.

2.1 Decomposition method

In Figure (1) the schematic diagram of the decomposition method is shown. The incident acoustic plane wave is propagating in the inlet pipe with sound intensity S_{AA} ; part of this wave will pass through the acoustic filter and a transmitted wave of intensity S_{CC} will be propagating in the outlet pipe. The other part of the incident wave will be reflected with sound intensity S_{BB} due to a change of impedance by the presence of the acoustic filter.

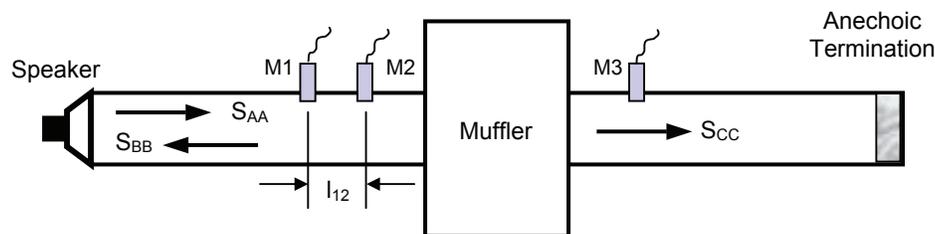


Figure 1: Schematic diagram of the set-up used in the decomposition method

Symbolically,

$$TL = 10 \log_{10} \frac{A_i S_{AA}(f)}{A_o S_{CC}(f)} \quad (1)$$

where $S_{AA}(f)$ is the power spectrum of the incident pressure, $S_{CC}(f)$ is the power spectrum of the out coming pressure, A_i and A_o are the inlet and outlet areas.

By the wave decomposition theory, the auto spectrum of the incident wave S_{AA} and reflected wave S_{BB} are calculated by Equations 2 and 3.

$$S_{AA}(f) = \frac{S_{11} + S_{22} - 2C_{12} \cos(kl_{12}) + 2Q_{12} \sin(kl_{12})}{4 \sin^2(kl_{12})} \quad (2)$$

$$S_{BB}(f) = \frac{S_{11} + S_{22} - 2C_{12} \cos(kl_{12}) - 2Q_{12} \sin(kl_{12})}{4 \sin^2(kl_{12})} \quad (3)$$

where:

S_{11} and S_{22} are the auto spectra of the total acoustic pressure at microphones 1 and 2, respectively;

Q_{12} and C_{12} are the real and imaginary parts of cross spectrum between microphones 1 and 2, respectively;

k is the wavenumber calculated by $k = \frac{2\pi f}{c}$, and l_{12} is the distance between microphones 1 and 2.

2.1 Two-source method

The two-source method was proposed by Tao and Seybert (2003), and its schematic diagram is shown in figure 2.

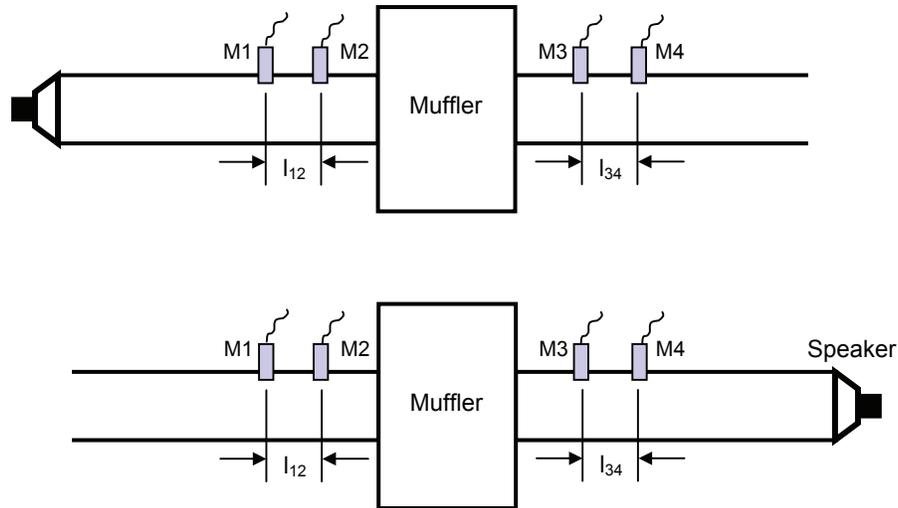


Figure 2: Schematic diagram of the two source method

This methodology is based on the transfer matrix approach. According to Munjal (1987), an acoustic element can be modeled by its four-pole parameters. The transfer matrix is:

$$\begin{bmatrix} p_1 \\ v_1 \end{bmatrix} = \begin{bmatrix} A & C \\ B & D \end{bmatrix} \begin{bmatrix} p_2 \\ v_2 \end{bmatrix} \quad (4)$$

where p_1 and p_2 are the sound pressure amplitudes at the inlet and outlet, v_1 e v_2 are the particle velocity amplitudes at the inlet and outlet and A, B, C and D are the four-pole parameters of the system (see figure 3).

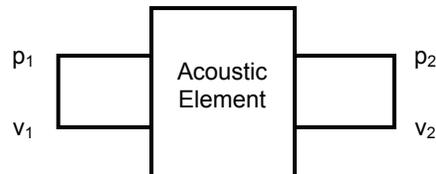


Figure 3: The four-pole representation

The TL can be expressed in terms of the four-pole parameters and tube areas using the equation (Pereira, 2003):

$$TL = 20 \log_{10} \left\{ \frac{1}{2} \left| A_{23} + \frac{B_{23}}{\rho c} + \rho c C_{23} + D_{23} \right| \right\} + 10 \log_{10} \left(\frac{A_i}{A_o} \right) \quad (5)$$

where:

$$A_{23} = \frac{\Delta_{34}(H_{32a}H_{34b} - H_{32b}H_{34a}) + D_{34}(H_{32b} - H_{32a})}{\Delta_{34}(H_{34b} - H_{34a})} \quad (6)$$

$$B_{23} = \frac{B_{34}(H_{32a} - H_{32b})}{\Delta_{34}(H_{34b} - H_{34a})} \quad (7)$$

$$C_{23} = \frac{(H_{31a} - A_{12} H_{32a})(\Delta_{34} H_{34b} - D_{34}) - (H_{31b} - A_{12} H_{32b})(\Delta_{34} H_{32a} - D_{34})}{B_{12} \Delta_{34} (H_{34b} - H_{34a})} \quad (8)$$

$$D_{23} = \frac{B_{34} [(H_{31a} - H_{31b}) + A_{12} (H_{32b} - H_{32a})]}{B_{12} \Delta_{34} (H_{34b} - H_{34a})} \quad (9)$$

where $H_{ij}(f)$ are the transfers functions for the (a) and (b) configurations of figure 3 and can be expressed as:

$$H_{ij} = \frac{G_{ij}(f)}{G_{ii}(f)} \quad (10)$$

$G_{ij}(f)$ are the cross spectra measured between microphones at positions i and j, and $G_{ii}(f)$ are the auto spectra measured by microphones at position i. Assuming that flow can be neglected, the four poles for elements 1-2 and 3-4 can be expressed as:

$$\begin{bmatrix} A_{12} & B_{12} \\ C_{12} & D_{12} \end{bmatrix} = \begin{bmatrix} \cos(kl_{12}) & j \rho c \sin(kl_{12}) \\ \frac{j \sin(kl_{12})}{\rho c} & \cos(kl_{12}) \end{bmatrix}, \quad \Delta_{12} = 1 \quad (11)$$

$$\begin{bmatrix} A_{34} & B_{34} \\ C_{34} & D_{34} \end{bmatrix} = \begin{bmatrix} \cos(kl_{34}) & j \rho c \sin(kl_{34}) \\ \frac{j \sin(kl_{34})}{\rho c} & \cos(kl_{34}) \end{bmatrix}, \quad \Delta_{34} = 1 \quad (12)$$

where,

l_{12} is the microphone spacing for positions 1 and 2;
 l_{34} is the microphone spacing for positions 3 and 4.

2.3 Two-load method

The two-load method uses the same mathematical formulation presented in the previous section, but in this case we do not need to change the sound source from one termination to the other. Two different impedance terminations must be created to obtain the transmission loss characteristics of the acoustic filter, see figure 4. The impedance difference needs to be significant, increasing or decreasing the value in order for the method to work properly.

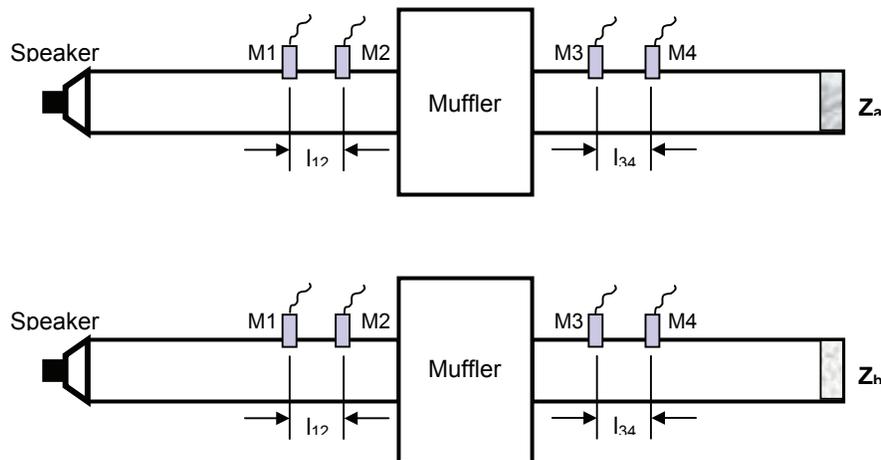


Figure 4: Two-load method set-up

2.4 Crocker's Method

The transmission loss by Crocker's method is defined by equation 13. This method requires an anechoic termination for measuring the TL.

$$TL = 20 \log \left| \frac{\exp(jkl_{12}) - H_{12}}{\exp(jkl_{12}) - H_{34}} \right| + 10 \log \left| \frac{G_{11}}{G_{33}} \right| + 10 \log \left| \frac{A_i}{A_o} \right| \quad (13)$$

where l_{12} is the distance between the two microphone positions 1 and 2, H_{12} is the complex transfer function between points 1 and 2, H_{34} is the complex transfer functions between points 3 and 4, G_{11} and G_{33} are the complex power spectral densities measured at points 1 and 3. The complex transfer functions H_{12} can be estimated by (Chu, 1986):

$$H_{12} = H_{1F} H_{F2} \quad (14)$$

where, H_{1F} is the complex transfer function between the signal from the microphone placed at position 1 and the excitation source signal, H_{F2} is the complex transfer function between the excitation source signal and the microphone placed at position 2.

3. NUMERICAL AND EXPERIMENTAL RESULTS

For this research, the transmission loss methodologies presented in the previous section have been used in order to measure the TL of a compressors muffler.

The numerical and experimental results obtained are presented in the next sections. To validate numerical results an experimental test rig was designed. Figure 5 shows the experimental set up.

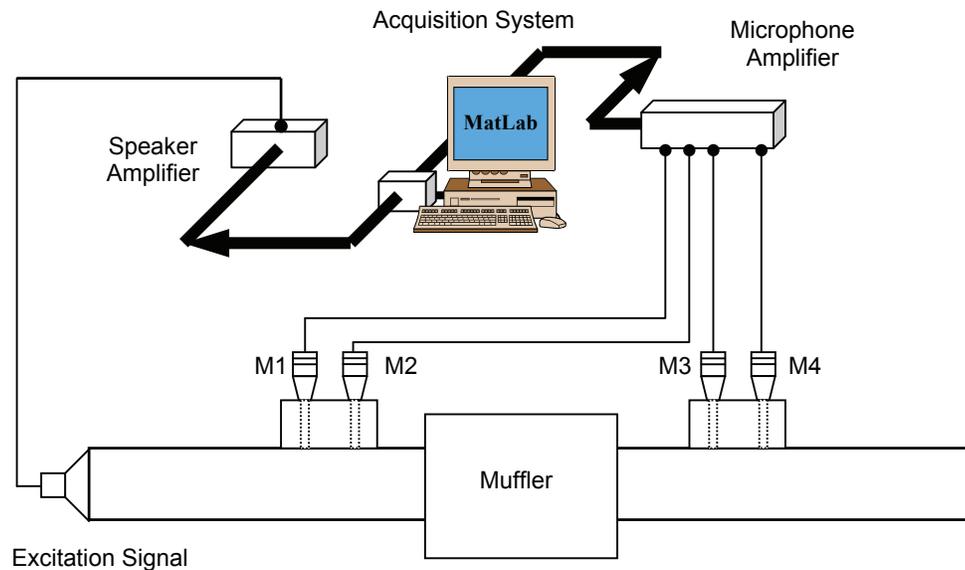


Figure 5: Experimental set-up

3.1 Probe microphone

Probe microphones are used in situations in which the measurements are difficult to perform using a common microphone, for example in ducts or cavities which have small dimension and are difficult to access.

Microphones are necessary for the experimental study of the transmission loss methods. In general, the compressor muffler dimensions are small and the use of a common microphone is not possible. For this reason it was necessary to design adapters for these microphones. In figure 6 is shown an FE mesh of the designed probe microphone.

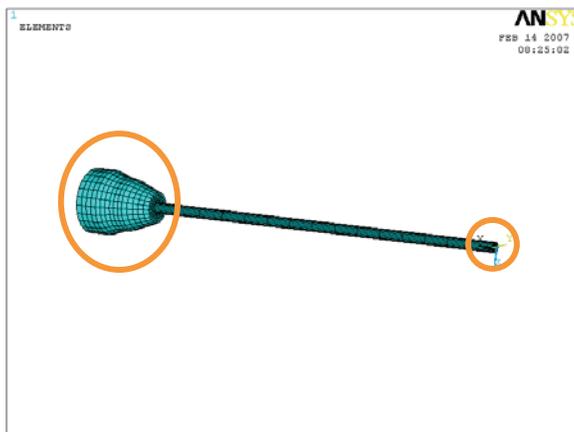


Figure 6: Probe microphone FE mesh

3.2 Muffler numerical results

The Ansys® software was used to simulate the compressor mufflers. The FE model in was built utilizing the element Fluid30, without fluid/structure interaction - in this analysis only the acoustic cavity was modeled. The boundary conditions applied were pressure at the inlet, admittance and impedance at the outlet. These last boundary conditions simulated the anechoic termination. The FE mesh and the boundary conditions can be seen in Figure 7.

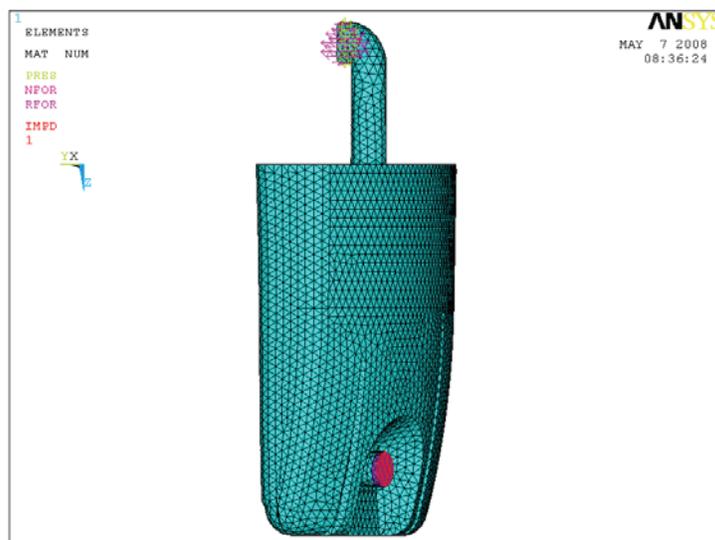


Figure 7: Finite element mesh and boundary conditions

The software Ansys® was used to run the harmonic analysis for a frequency range from 0 to 5 KHz. The results for transmission loss, using the decomposition method, can be seen in figure 8.

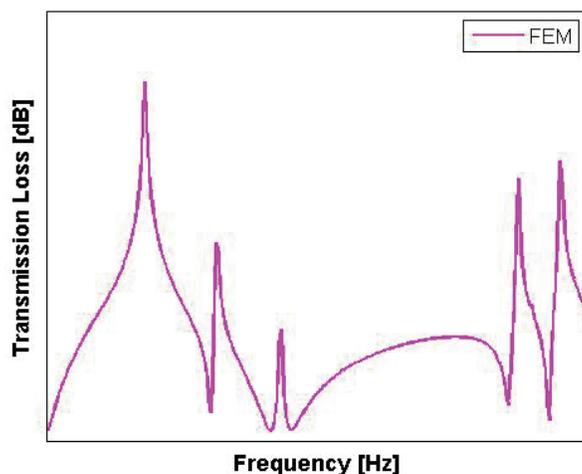


Figure 8: Numerical transmission loss - Decomposition method

3.3 Experimental results

The two-load method, Crocker's method and the decomposition method were used for obtaining experimentally the transmission loss of the compressor muffler. The four signals were measured with $\frac{1}{2}$ " probe microphones (B&K 4192 with sensitivity 12.5 mV/Pa) by an acquisition system VXI® and were processed by the software Matlab®. The transmission loss measured with the three methods investigated can be seen in figure 9.

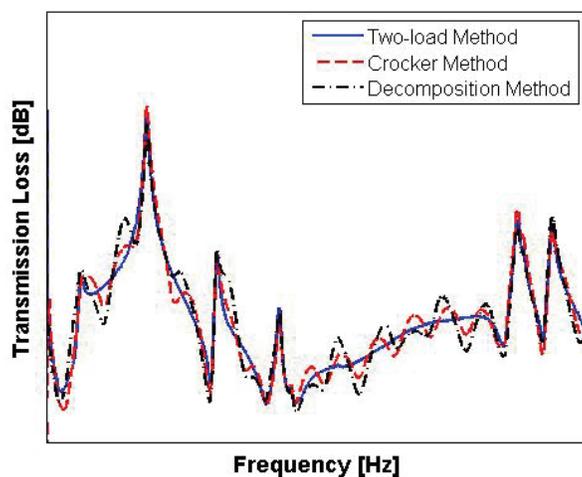


Figure 9: Experimental results for the acoustic filter

In this figure it can be observed that the Crocker method and the decomposition method do not present good results when compared to the two-load method. These discrepancies can be explained by the anechoic termination that these methodologies required. The two-load method shows a good result because it does not need an anechoic termination.

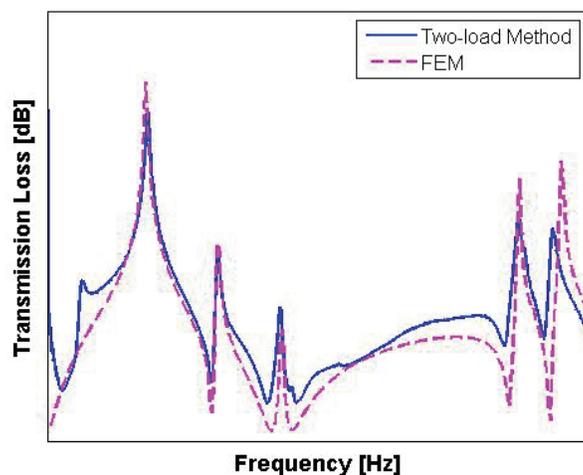


Figure 10: Comparison between numerical and experimental results

4. CONCLUSIONS

In this paper were exposed a numerical and experimental study of the sound transmission loss for mufflers applied in hermetic compressors. The results were obtained with a Finite Element model and by wave theory in ducts. Due to the difficulties to build an anechoic termination, the experimental results showed us that the two-load method was the most appropriate for this work, presenting a good correlation when compared with numerical results.

About the employed instrumentation, one important aspect was the use of a probe microphone, developed for the task as described in section 3.1, which made measurements possible in ducts with small diameters and presented acceptable results. The probe microphones were not calibrated, because all measurements were done the same way, so that the distortion inserted was the same in all microphone probes and their effect canceled on the TL calculation.

REFERENCES

- Chu, W.T., "Transfer function technique for impedance and absorption measurements in an impedance tube using a single microphone" *Journal of the acoustical society of America*, Vol. 80, No. 2, pp.555-560, 1986.
- Gerges, S. N. Y. "Ruído: Fundamentos e Controle". 2ed. Florianópolis, 2000.
- Gerges, S. N. Y., Jordan, R. "Muffler Modeling by Transfer Matrix Method and Experimental Verification". *Journal of the Brazilian Society of Mechanical Sciences and Engineering*. vol. XXVII, number 2, April- June 2005.
- Munjjal, M. L. "Acoustics of Ducts and Mufflers". John Wiley & Sons, 1987.
- Pereira, A. R. S. "Determinação da perda de transmissão sonora em silenciadores automotivos por matrizes de transferência". *Dissertação mestrado em Engenharia Mecânica*. Universidade Federal de Santa Catarina. Florianópolis 2003.
- Tao Z, Seybert A. F. "A review of current techniques for measuring muffler transmission loss". SAE International, 2003.

ACKNOWLEDGEMENT

The authors acknowledge the financial support of *Tecumseh do Brasil Ltda* and the support and collaboration of the *Departamento de Mecânica Computacional - DMC-FEM-UNICAMP*.