Experimental Study and Prediction of Insertion Loss of Acoustical Enclosures

Krzysztof KOSAŁA, Leszek MAJKUT, Ryszard OLSZEWSKI
AGH University of Science and Technology,
al. A. Mickiewicza 30, 30-059 Kraków,
kosala@agh.edu.pl, majkut@agh.edu.pl, olszewsk@agh.edu.pl

Abstract

The article presents the results of an experimental study and calculations, using theoretical models, of the insertion loss of acoustical enclosures. The research used a developed prototype stand for testing acoustical enclosures. The sound power levels of the source without and with the enclosure, needed to determine the insertion loss, were determined by the approximate method in accordance with standard requirements. To calculate of the insertion loss for enclosures with sound absorbing and insulating walls, a known calculation model using the transmission loss of baffles was used. A new calculation model for enclosures with sound insulating walls is proposed in the article.

Keywords: acoustical enclosures, prediction of insertion loss, sound transmission loss

1. Introduction

Among the acoustical enclosures used to reduce the noise level of machines and devices, there are sound insulating enclosures and sound absorbing and insulating ones [1]. In the construction solutions of sound insulating enclosures, materials resistant to the penetration of sound waves are used, while in sound absorbing and insulating enclosures, sound absorbing materials are used, which act as lining or sound-absorbing cores in layered baffles.

The basic parameter determining the performance of acoustical enclosures is insertion loss [2], which can be determined from acoustic measurements, as well as being calculated using theoretical models. One of the known models, which relates to sound absorbing and insulating enclosures, is a model based on transmission loss of its walls [2,3]. The article presents the verification of this model and a proposal for a new calculation model for enclosures with sound insulating walls is also shown. The results of calculations were verified by referring them to acoustic measurements carried out on the developed prototype stand for testing acoustical enclosures [4].

2. A prototype test stand for testing acoustical enclosures and walls

The basic element of the enclosure is a steel frame in the shape of a cube, allowing the installation of five walls measuring 700 × 700 mm with the thickness 1-90 mm. Each of the tested walls is tightened, through a rubber seal, to the enclosure frame using 10 × 10 mm square steel frames and a set of 12 holdfast mechanisms. Inside the enclosure frame is an omnidirectional sound source, which consists of 6 speakers mounted in a cubic enclosure (Fig. 1a).

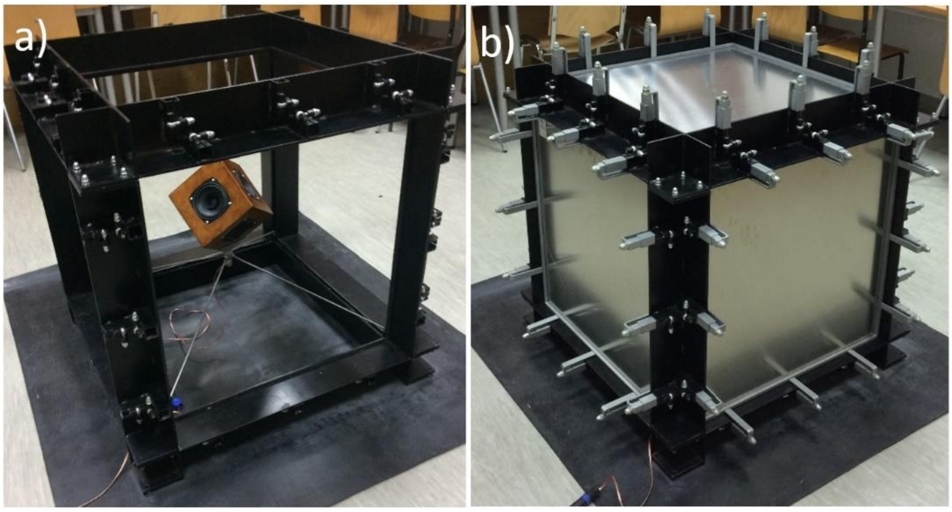

Figure 1. View of the enclosure: a) steel frame without walls and with an omnidirectional sound source, b) enclosure with walls of mineral wool-aluminium composition

An enclosure with a set of five identical walls was tested for five variants – different baffle types. Steel, aluminium and plexiglass plates were the sound insulating baffles. Sound absorbing and insulating baffles, consisting of two layers - mineral wool lining and plates of steel and aluminum, were installed to the enclosure frame as a sound absorbing layer from the sound source side (Fig. 1b). The designations of the tested walls along with their material data are shown in Table 1.

Table1. Parameters of the tested enclosure walls

Id.*	Layers of the enclosure wall	Plate thickness, h, m	Plate density, ρ_M, kg/m^3	Wall thickness, g, m	Young's modulus, E, GPa	Poison's ratio, ν	Loss factor, η
A1	Steel	0.001	7850	0.001	207	0.3	0.01
A2	Aluminium	0.002	2800	0.002	70	0.35	0.01
A3	Plexiglass	0.005	1150	0.005	3.5	0.35	0.02
B1	Mineral wool	0.05	110	0.051	-	-	-
	Steel	0.001	7850		207	0.3	0.01
B2	Mineral wool	0.05	110	0.052	-	-	-
	Aluminium	0.002	2800		70	0.35	0.01

*The A(1-3) designation refers to sound insulating walls and the B(1,2) designation refers to sound absorbing and insulating walls (these walls are mounted to the enclosure with a sound absorbing layer from the source side).

3. Experimental study of insertion loss of the enclosure

3.1. Measurement methodology

Acoustic tests were carried out in a room with a capacity of 79 m^3, as shown in Fig. 1. The signal in the form of white noise, generated in the Audacity program by an audio interface (EDIROL UA-5) and amplifier (Bruel and Kjaer 2716-C), was fed to an omnidirectional sound source. A SVAN 945A sound level meter was used to measure sound pressure levels to determine the power levels of the source without and with the enclosure, and finally to determine the performance of the acoustical enclosure. The sound power levels were determined using the approximate method in accordance with PN-EN ISO 3746:1999, taking into account the correction for background noise K1 and the environmental correction K2 [5].

The performance of the acoustical enclosure in terms of insertion loss (IL) was determined using the formula [2, 4]:

$$IL = 10\log\left(\frac{W_0}{W_E}\right) = L_{W0} - L_{WE}, \qquad dB \tag{1}$$

where: W_0, W_E – the sound power radiated by the unenclosed and enclosed source, respectively, L_{W0}, L_{WE} – the corresponding sound power levels.

3.2. Results

Fig. 2 shows the spectral characteristics of IL in 1/3 octave frequency bands, determined for five enclosure variants, as described in Table 1.

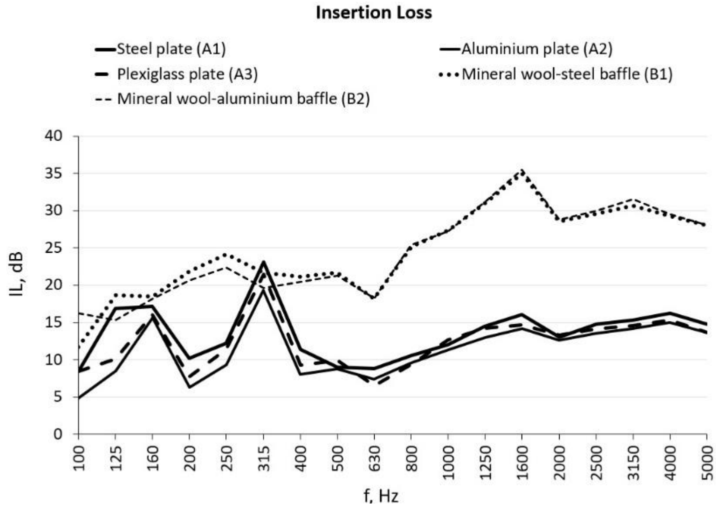

Figure 2. Spectral characteristic of Insertion Loss of tested enclosures with sound insulating walls A1, A2 and A3 and sound absorbing and insulating walls B1 and B2

As can be seen from Fig. 2, the spectral characteristics of IL of enclosures with walls containing a sound absorbing lining (B1 and B2) show a flatter course in the lower frequency range (below 500 Hz) in relation to enclosures with sound insulation walls that reflect sound waves (A1, A2 and A3).

4. Prediction of insertion loss

4.1. Sound absorbing and insulating enclosures

The performance of acoustical enclosures with sound absorbing and insulating walls can be calculated using a simplified theoretical model [2]:

$$IL = 10\log(\alpha) + TL \ \text{[dB]}, \tag{2}$$

where: TL – the sound transmission loss of the enclosure wall, dB, α– average sound absorption coefficient of the internal side of the enclosure walls.

For calculating the sound transmission loss (TL) of the walls B1 and B2 (Table 1) and the average sound absorption coefficient α, the AFMG SoundFlow software was used [6].

Taking into account the assumption that each enclosure has leaks [2,3], the performance of the sound absorbing and insulating enclosure IL_{ai} can be determined from the formula:

$$IL_{ai} = 10\log\frac{\alpha}{10^{-0.1TL} + \beta} \ \text{[dB]}, \tag{3}$$

where: β – coefficient determining the ratio of the leakage area to the wall area [2], depending on the single-number weighted sound reduction index R_w of the wall, β <<1, which can be calculated from:

$$\beta = e^{-0.23R_w} \tag{4}$$

Figures 3 and 4 show the calculated spectral characteristics of the insertion loss of sound absorbing and insulating enclosures, in relation to the transmission loss of their walls.

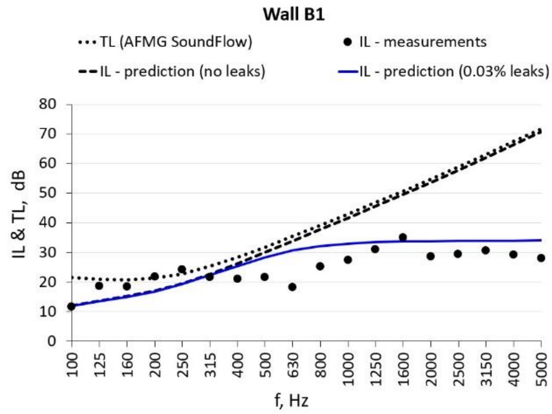

Figure 3. Comparison of measured and calculated enclosure insertion loss (IL) and wall sound transmission loss (TL). Enclosure consisting of five identical B1 walls.

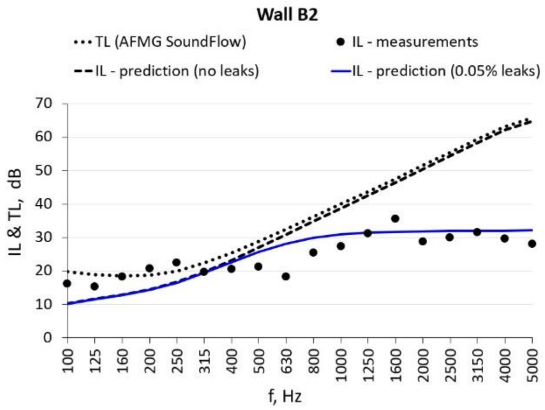

Figure 4. Comparison of measured and calculated enclosure insertion loss (IL) and wall sound transmission loss (TL). Enclosure consisting of five identical B2 walls.

It can be seen from the graphs (Figures 3 and 4) that for sound absorbing and insulating enclosures, assuming the leakage of walls, related to the parameter R_w of the enclosure wall, the values of insertion loss obtained from calculations are close to the value of this parameter obtained from measurements.

4.2. Sound insulating enclosures

To calculate the performance of enclosures with sound insulating walls, the authors of the article proposed a new formula:

$$IL_i = 10\log\frac{\bar{\alpha}_{rand}}{10^{-0.1TL} + \beta}\ \text{[dB]}, \tag{5}$$

where: $\bar{\alpha}_{rand}$ - the random incidence sound absorption coefficient of bare enclosure walls [2]

$$\bar{\alpha}_{rand} = \frac{1}{1 + \left(\frac{1}{52}\right)\left[\frac{\omega\rho_s}{(\rho_0 c_0)}\right]^2} + \frac{2\pi\sqrt{12}c_0^2\rho_0 c_0\sigma_{rad}}{c_L\rho_M h^2\omega^2} + \\ + \frac{\rho_0 c_0\sigma_{rad}}{\rho_0 c_0\sigma_{rad} + \rho_s\omega\eta} + 0.72(10^{-4})\sqrt{\omega} \tag{6}$$

where: ω – angular frequency, s^{-1}, ρ_s – surface density, kg/m^2, ρ_0 – air density, kg/m^3, ρ_M – material density, kg/m^3, c_0 – speed of sound in the air, m/s, σ_{rad} – radiation efficiency [2], c_L – longitudinal wave speed, m/s [2] and η - loss factor.

Figures 5, 6 and 7 show the calculated spectral characteristics of insertion loss of sound insulating enclosures in relation to the transmission loss of their walls.

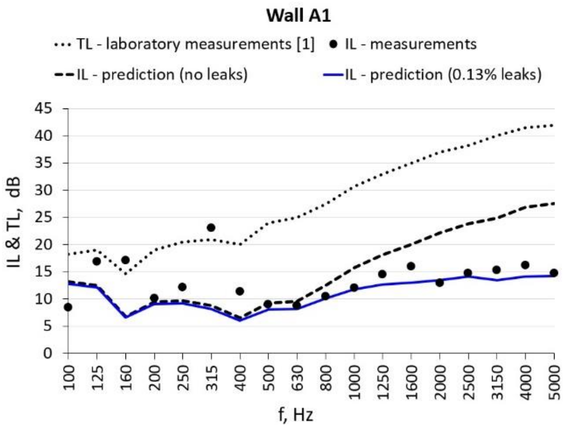

Figure 5. Comparison of measured and calculated enclosure insertion loss (IL) and wall sound transmission loss (TL). Enclosure consisting of five identical A1 walls.

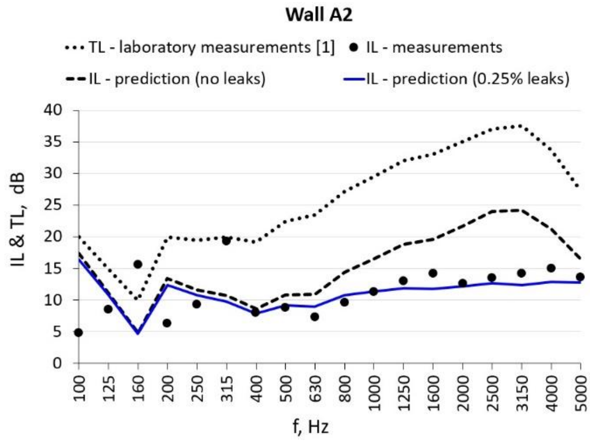

Figure 6. Comparison of measured and calculated enclosure insertion loss (IL) and wall sound transmission loss (TL). Enclosure consisting of five identical A2 walls.

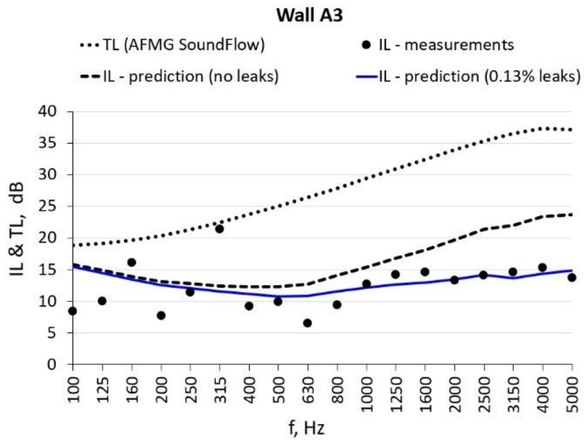

Figure 7. Comparison of measured and calculated enclosure insertion loss (IL) and wall sound transmission loss (TL). Enclosure consisting of five identical A3 walls.

In the case of sound insulation walls (Figures 5, 6 and 7), considering the leaks of the walls, the values of the insertion loss obtained from the calculations are close to the values of this parameter obtained from measurements in the range of central and higher frequencies (above 400 Hz).

5. Conclusions

Preliminary tests of the acoustic performance of several sound insulating and sound absorbing and insulating enclosures were carried out. For this purpose, a developed prototype of the test stand was used to test the acoustical enclosures. As part of the preliminary tests, an approximate method was used to determine the sound power levels of the unenclosed and enclosed sound source, necessary for the calculation of the insertion loss. In the case of sound absorbing and insulating walls, commercial software was used to calculate the transmission loss, which was then used to predict the insertion loss of the enclosure.

The use of a simplified formula for determining the insertion loss for acoustical enclosures shows a fairly good match of the spectral characteristics to the measurement results, when the relevant leakage values are taken into account in the calculations, depending on the single-number weighted sound reduction index R_w of the wall.

In the case of the insertion loss prediction model for enclosures with sound insulating walls, proposed in the article, the calculation results compare well with the measurement results, however, only for the central and higher frequency ranges. Significant discrepancies in the results of calculations and measurements can be observed for lower frequencies, which requires further modeling to take into account the acoustic resonances of the enclosure.

Acknowledgements

The project described in this paper has been executed within the project No. 16.16.130.942.

References

1. J. Sikora, *Rubber layers in solutions of vibroacoustic protections* (in Polish), AGH, Kraków 2011.
2. I.L. Ver, L.L. Beranek, *Noise and vibration control engineering – principles and applications*, John Wiley & Sons, Inc, Hoboken, New Jersey 2006.
3. H.S. Kim, et al., *A simple formula for insertion loss prediction of large acoustical enclosures using statistical energy analysis method*, Int. J. Nav. Arch. Ocean, 6.4 (2014) 894 – 903.
4. K. Kosała, R. Olszewski, L. Majkut, A. Flach, *Testing of the acoustic properties of a sound insulating enclosure with single and double-layer walls*, Konf. WibroTech 2019, Kraków-Zawiercie.
5. PN-EN ISO 3746:1999 – Akustyka. Wyznaczanie poziomów mocy akustycznej źródeł hałasu na podstawie pomiarów poziomu ciśnienia akustycznego. Metoda orientacyjna z zastosowaniem otaczającej powierzchni nad płaszczyzną odbijającą dźwięk.
6. AFMG SoundFlow Software Manual. Ahnert Feistel Media Group 2011.