

Suggested enhancements for industrial silencers characterization at low frequencies

Jean-Christophe LE ROUX, François FOHR¹, Eric PORTIER

Centre de Transfert de Technologie du Mans

ABSTRACT

To design ventilation/air conditioning systems of collective or industrial buildings, the acoustic designers need to know with enough accuracy the performance of silencers conventionally used to treat the noise generated by the fan units. The experimental methodologies for determining acoustic attenuation and the regenerated noise in flow by the silencers are described by standards EN ISO 7235 ASTM in Europe and E477 in the United States. These procedures are based on the use of a reverberation room where the measurements of noise power emitted by the connected test duct are made. Recent inter-laboratory comparisons showed a very large dispersion of the measured insertion loss particularly in the first frequency bands (63 and 125 Hz). Error factors are well identified: change of the modal behavior of the test duct with or without the silencer, spatial heterogeneity of the sound field in the reverberation room and sound power loss by radiation from the walls of the test duct. The Centre de Transfert de Technologie du Mans, which implements and develops a bench dedicated to the qualification of the silencers since ten years, presents in this article the results of a recent methodological study which outlines the various error factors and their influence on the measuring acoustic and aeroacoustics characteristics of industrial silencers. Based on this analysis, changes are proposed to significantly reduce low frequency error factors by using an original anechoic termination design.

Keywords: silencer, ISO 7235, insertion loss, transmission loss, anechoic termination, experimental procedure

1. INTRODUCTION

The characterization of silencers for industrial ventilation systems is governed by the European standard EN ISO 7235: 2009 (1) and the American standard ASTM E477 (2). These standards describe an alternative method for measuring the insertion loss of the silencers by comparing two sets of measurements first with the silencer and with a smooth duct in place of the silencer. The recommended method to evaluate the acoustic power output of the test line consists of using a reverberation room in which will be measured spatial and temporal averaged sound pressure.

Given the current dimensions of the tested silencers (of the order of 1 m²), the acoustic propagation is multimodal from low frequencies and measuring methods using microphones in wall ducts cannot be implemented. Finally, the method recommended by the standard remains the only applicable method to characterize the acoustic properties of silencer over a wide frequency range.

Inter-laboratory comparisons made in North America (3) have shown very significant dispersion of measurement results in the low frequency range (reproducibility standard deviation higher than 10 dB in the first octave bands at 63 Hz and 125 Hz). However, the acoustic qualification of the silencer at low frequencies is an important issue because it is particularly in this area that differentiates the performances, good attenuations of medium and high frequencies are generally easy to achieve with conventional silencers.

Error factors of low frequencies measurements are well identified. It is primarily:

- The difference between the acoustic modal behavior of the test line in the presence or not of the silencer,
- Changes in the acoustic source behavior with or without silencer in test,
- Quality of the diffuse field of the reverberation room in the first frequency bands,
- Acoustic power loss due to the radiation of the various components of the test line, particularly the

¹ ffuhr@cttm-lemans.com

substitution duct.

In a previous study (4), we have highlighted the influence of these different error sources on a $0.3 \times 0.5 \text{ m}^2$ test duct. It emerged a set of recommendations for improving the quality of measurements especially a methodology dedicated to the low frequencies (plane waves conditions) by using an anechoic termination at the end of the line test.

This proposal, very efficient, complicates significantly the testing procedure requiring the mounting of two separate test configurations and the use of 4 additional microphones.

The new proposal made in this article represents a more simple implementation with small modifications of standard test bench and an identical measurement procedure. The purpose is to place an anechoic termination for low frequencies between the end of the test line and the reverberation room to improve significantly the measurement conditions.

The original principle of the anechoic termination used for this application has been proposed in 1989 by researchers from LAUM (5) and recently developed in partnership with CTTM and LAUM (6). The features of this anechoic termination are that it's well adapted to the very low frequencies and particularly compact.

The main objective of the study presented in this article is to validate the application of the standard procedure in the presence of this anechoic termination for the entire frequency range.

This experimental setup is not suitable for measurements in flow conditions. However, for most applications, the acoustic performances of the silencers are not influenced by the flow with speeds less than 20 m/s.

2. THE ANECHOIC TERMINATION

The anechoic termination design principles have been described in previous publications (5, 6).

The development of this anechoic termination has been made initially on small models for pipes diameters from 30 to 50 mm. In these dimensions, experimental studies have led to characterize the performance of the anechoic termination in a wide frequency range only limited by the occurrence of transverse modes. It thus appeared that for a minimum reflection coefficient (close to zero) in the first frequency bands, it appears a "cut" frequency from which the reflection coefficient rises significantly.

This is the case for example of the anechoic termination performed for the ducts of 35 mm diameter with the measured reflection coefficient shown in Figure 1.

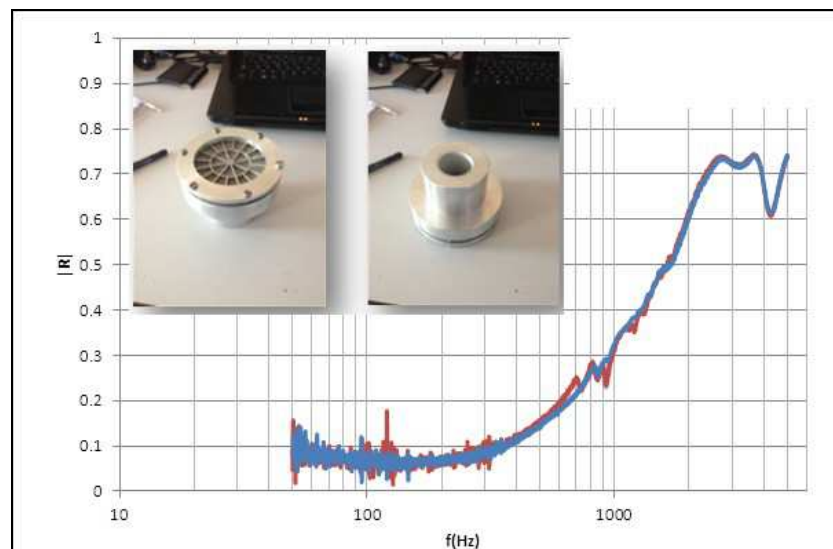


Figure 1 – Reflection coefficient of an anechoic termination adapted to the ducts of 35 mm diameter

The declination of this principle of anechoic termination in larger dimensions has been validated for a section of $0.5 \times 0.3 \text{ m}^2$ (Figure 2).

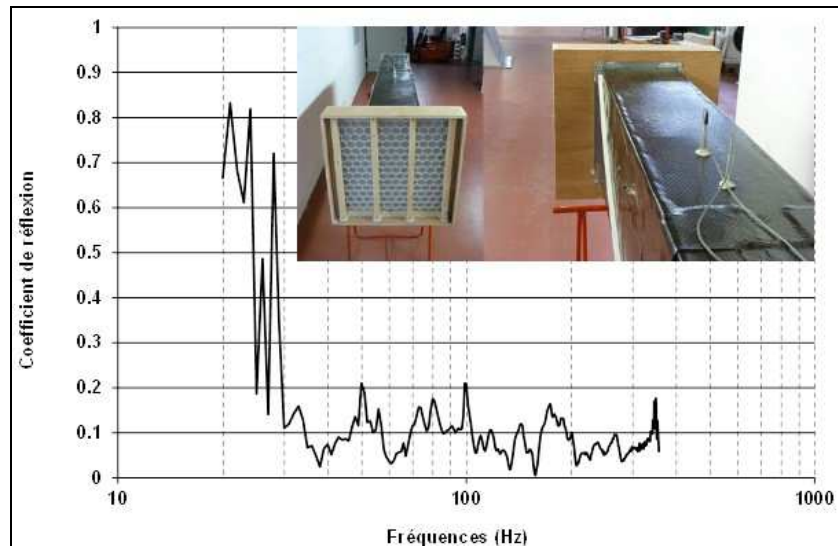


Figure 2 - Reflection coefficient of an anechoic termination for ducts of 0,5 x 0,3 m² area

The latest manufactured anechoic termination benefited from improvements in the design with an acoustic treatment of medium and high frequencies over a short length immediately upstream of the termination. These improvements have extended their performances up the frequency spectrum. The model created for this study (Figure 3), adapted to a duct diameter of 160 mm, has a reflection coefficient of less than 0.2 between 40 Hz and 1 kHz.

These achievements show that it is probably possible to extend the performance of such anechoic termination to the entire frequency range.

Similarly, anechoic terminations adapted to large duct sections (of order of 1 m²) are probably feasible. For these large models, the difficulty will be to determine a methodology to qualify them on a wide range of frequencies, in conditions of multimodal propagation.

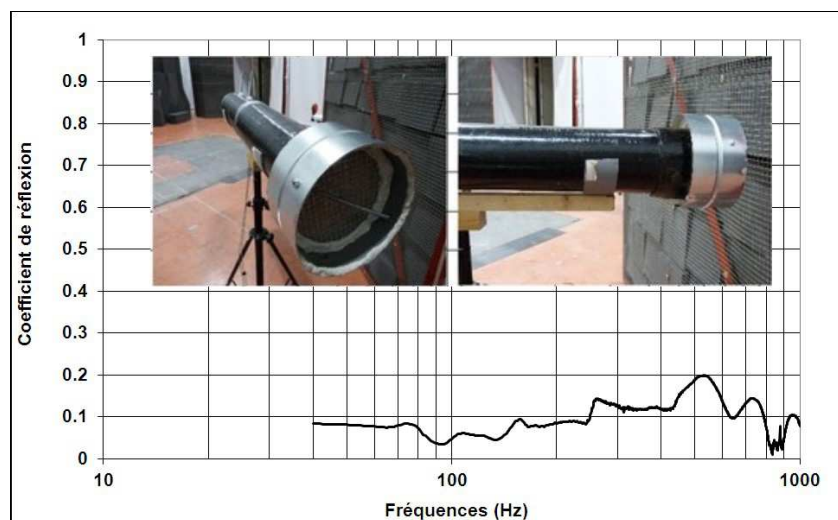


Figure 3 - Reflection coefficient of an anechoic termination adapted to the ducts of 160 mm diameter

3. THE TEST BENCH WITH ANECHOIC TERMINATION

The test bench used for the tests consists (Figure 4) of a main test section of 160 mm diameter connected upstream to a broadband acoustic source and downstream to an anechoic termination inserted between the test line and the reverberation room.

The choice of this duct dimension allows to performing measurements in plane wave condition over

a sufficiently wide frequency range up to about 1 kHz. For the most common industrial measurement, the dimensions of silencers and therefore the associated test line restrict the frequency range of the propagation plane wave at 200 or 300 Hz and it is difficult in this configuration of studying acoustic bass propagation phenomena.

To carry out the measurements at low frequencies, four microphones flush mounted in the inner walls of the duct are positioned on either side of the muffler tests.

Measurements of the acoustic power transmitted to the output of the test section are performed in the reverberation room of CTTM. With 350 m³ of interior volume, no parallel walls and a set of broadcasters, this room is qualified to be able to perform measurements in diffuse-field conditions from 100 Hz. A set of four microphones is distributed in the room for average sound pressure measurements.

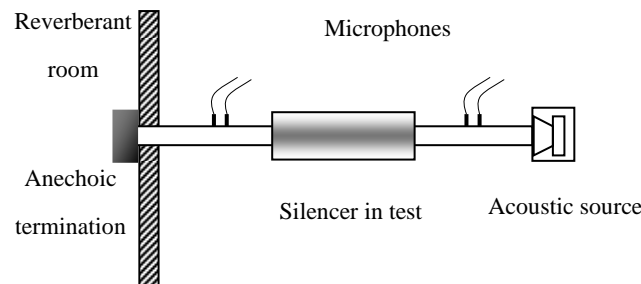


Figure 4 - Test bench

4. A CASE STUDY OF ABSORBING SILENCER

4.1 Experimental methodology

The silencer chosen as study case is very classic design. This is a circular silencer of 1 m long with 10 cm rockwool in periphery contained by a perforated grid to about 50%.

The objective of these tests is to demonstrate the influence of the standing wave ratio in the test ducts. Special care was given mounting and measurement conditions to minimize the better the influence of other sources of error:

- The emissivity of the ducts is limited by the use of rigid cylindrical pipes of small diameter,
- The measurement of the sound pressure in the reverberation room is obtained from a large number of averages to minimize standard deviations,
- The acoustic source is a constant acoustic flow source, insensitive to the test duct impedance variations.

The measurements are performed in the frequency range of 40 Hz-10 kHz using a source signal type pink noise.

Three series of tests are performed:

- with the silencer,
- with a smooth duct of same length,
- Without duct in place of the silencer (shortened line).

The tests are repeated after replacing the anechoic termination by a simple adaptation cone which increases the output section of a 2.5 over a length of 30 cm. We chose to perform tests in a small section of duct to widen the frequency band of observing. The impedance adaptation cone is scaled of parts used in reality of industrial silencers measures.

The figure 5 compares the reflection coefficients measured with and without termination anechoic when the test duct is connected to the reverberation room.

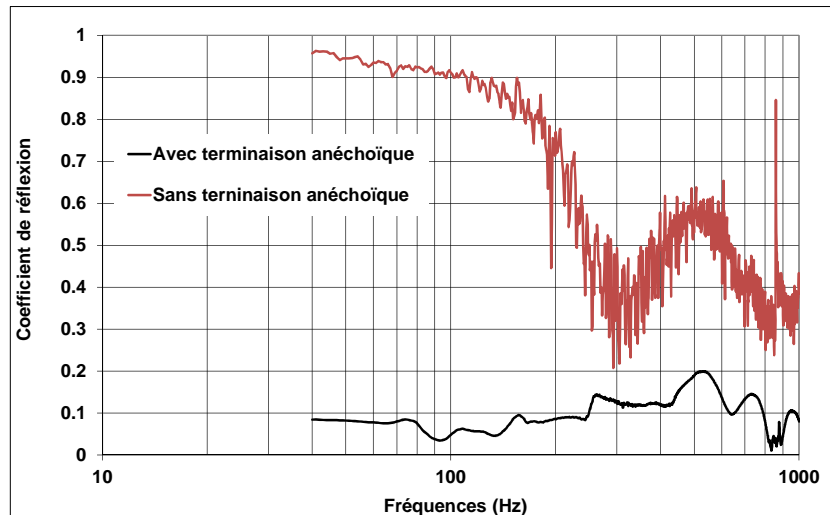


Figure 5: Reflection coefficient at the end of the test duct with and without anechoic termination

4.2 Transmission loss measurement

Transmission loss measurements with the anechoic termination represent the reference to determine the attenuation properties of the silencer in the frequency domain of the plane wave propagation (40 Hz - 1 kHz). It is performed by applying the conventional method of determination of the silencer scattering matrix from the measured transfer functions provided by two pair of microphones located upstream and downstream the silencer.

This measurement will be used to evaluate the different test configurations in following the study.

Figure 6 shows the result of this measurement for third band octaves between 50 Hz and 800 Hz.

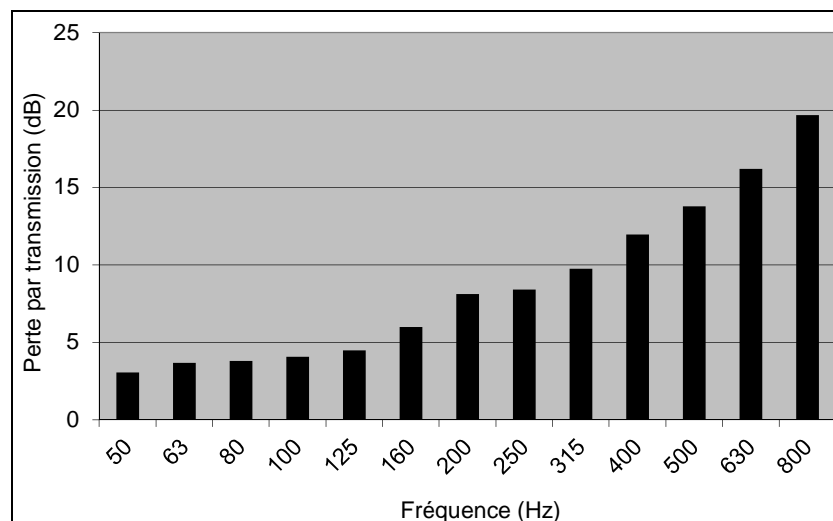


Figure 6 – Transmission loss of the tested silencer

4.3 Insertion loss measurement with and without anechoic termination

First, the insertion loss is measured with the anechoic termination, and when it is replaced by an adaptation cone. Figure 7 shows the results obtained by third octave bands in the frequency range of plane waves. These measurements show that the use of the anechoic termination allows bringing closer insertion loss and transmission loss values with gaps that remain, however, significant.

This result is not surprising because in the experimental methodology for determining the insertion loss, replacing the tested silencer by a substitution duct changes strongly the acoustic impedance seen by the source and consequently changes sound power injected into the test section, even if the source is invariant. This variation of the sound power injected in the test duct is mainly due to the

modification of silencer input impedance but also to the termination impedance of the test duct.

To highlight these phenomena we measured the power injected by the source in different configurations

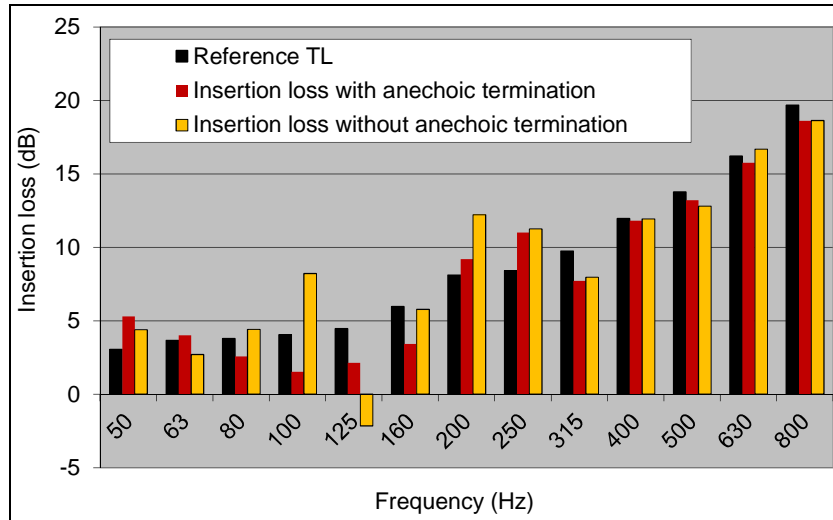


Figure 7 : Insertion loss of the tested silencer with and without anechoic termination compared with the transmission loss

4.4 Consideration of the injected power

The power injected by the source in the test duct is measured using the pair of microphones placed upstream of the silencer.

Figures 8 and 9 compare the acoustic powers injected in the presence or not of the silencer respectively without and with an anechoic termination.

The differences with and without the silencer are logically much higher when not using anechoic termination. Indeed, in the latter case, the test duct termination reflection coefficient is close to 1. The very important standing waves ratio is greatly reduced with the silencer in place. The injected sound power is strongly impacted.

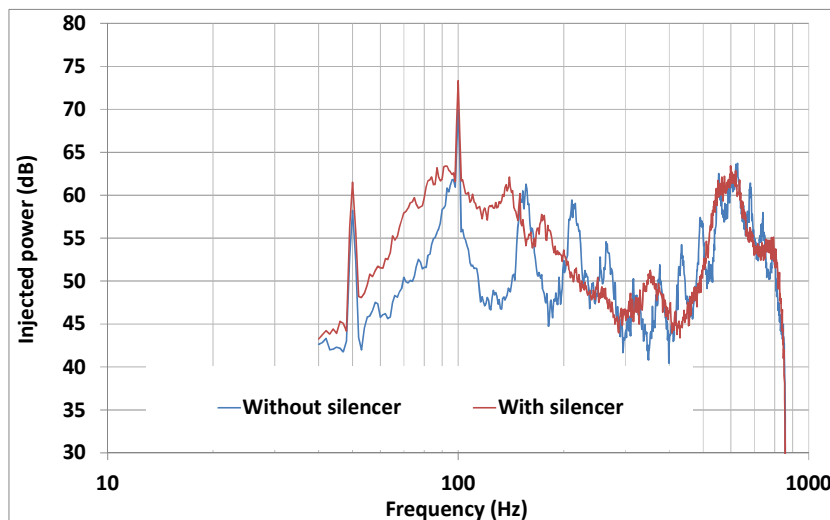


Figure 8: Measured injected power without anechoic termination

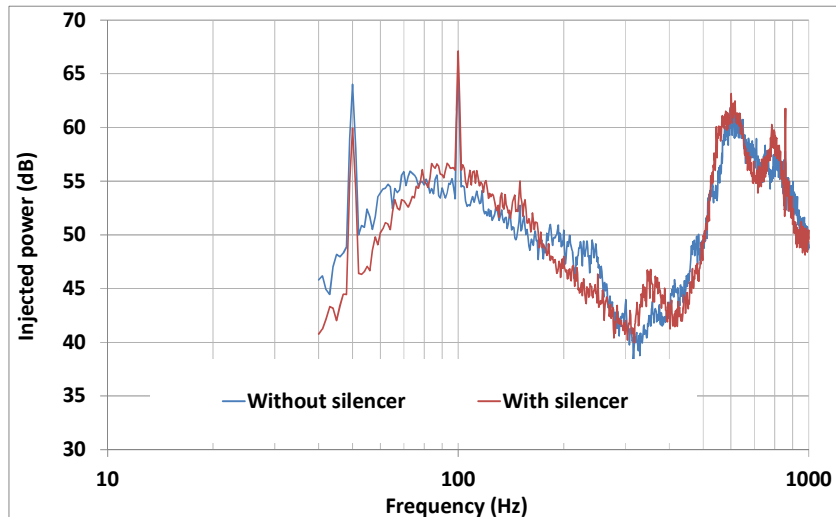


Figure 9: Measured injected power with anechoic termination

However, with the anechoic termination, the gaps remain significant and can explain the remaining differences between transmission loss and insertion loss. To verify this, we corrected the calculation of insertion loss by the difference of injected powers with and without silencer. The result of this correction is compared to the original measure on the figure 10. It is clear that taking into account the difference of injected power with and without silencer can effectively correct the insertion loss which is much closer to the transmission loss.

The latest differences that still exist between the two determinations are likely due to the lower quality of the diffuse field below 100 Hz in the reverberation room.

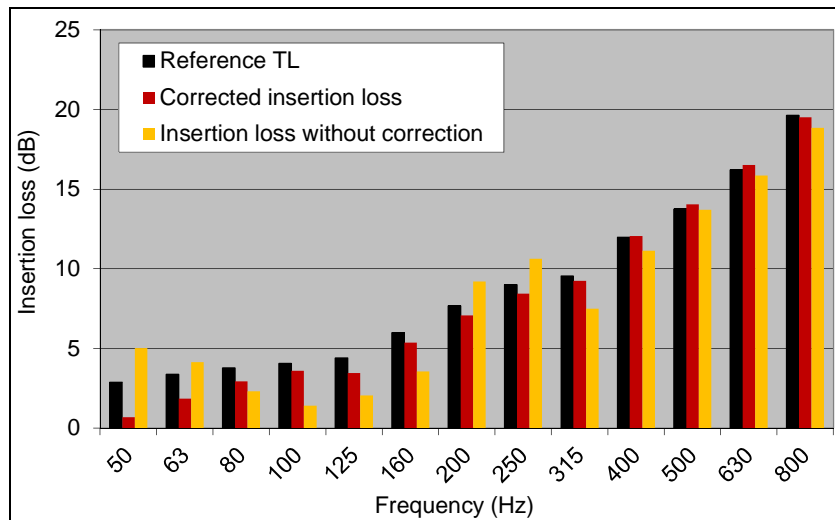


Figure 10: Insertion loss with and without correction by injected power

4.5 Measurements over the entire frequency range

The anechoic termination and its influence on the test procedure described by the ISO 7235 standard have been characterized only in the plane wave frequency domain with the determination of the scattering matrix taking into account the injected acoustic power. To estimate the impact of the anechoic termination for the whole frequency range defined by the standard, we compare in the graph of the figure 11 measurements with and without anechoic termination between 50 Hz to 10 kHz.

It appears that both determinations are consistent up to 4 kHz. However, for the last frequency bands, it is a significant gap reached 8-9 dB at 10 kHz. To date, we have not identified the cause of

these differences. It could be an important reflection coefficient of the anechoic termination in high frequencies. Unfortunately, the qualification of this parameter in the context of a multimodal acoustic propagation is not possible with conventional methods

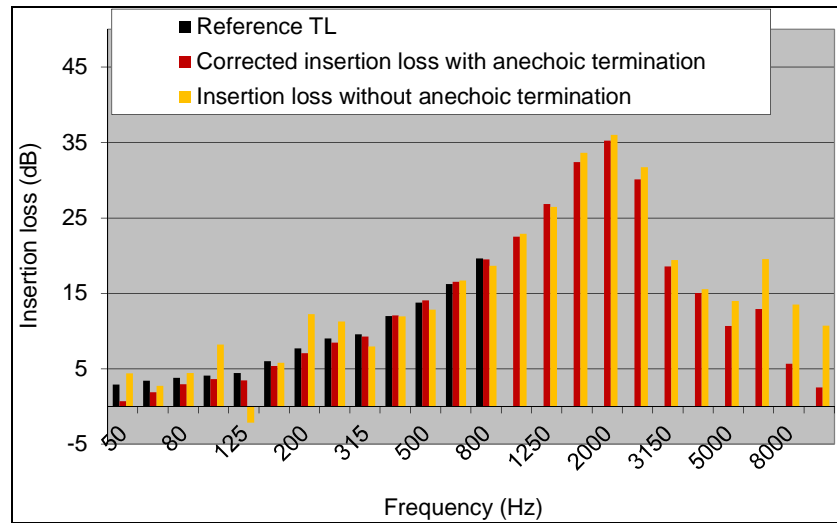


Figure 11: Insertion losses measured on the whole frequency range

5. CONCLUSION

The methodological study presented in this paper aims to highlight the main problem of the ISO 7235 standard which defines the procedures for measuring the insertion loss of absorbent silencers: the change in the standing wave ratio in the low frequencies in the test duct with and without the tested silencer.

To limit this high error factor, a first proposal is to use anechoic termination effective in very low frequencies. This anechoic termination, developed in recent years at the CTTM in partnership with the LAUM, proved successful in a wide frequency band and adaptable in large dimensions.

In the context of the standardized measurement of absorbent silencers, the use of this anechoic termination (compact) clearly improves measurement conditions. Its use is validated for a wide frequency range and provides a significant improvement in measurement accuracy at low frequencies.

Despite this, the measuring principle by substitution causes an error factor intrinsically linked to the variation in acoustic impedance at the input of the tested silencer. This impedance change causes a variation in the injected acoustic power in the test duct. We verified that taking into account the injected power variation further improves measurement accuracy. Implement this correction involves installing a pair of microphones between the acoustic source and the tested silencers.

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