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Correlation Between the Shape of Substitution Ducts and Insertion Loss of Silencers

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Abstract Silencers are typical devices used for the reduction of noise in ventilation systems, which can be found in almost all industrial, service or residential installations. Determination of acoustic parameters for specific HVAC devices, like silencers, is within the scope of specialised laboratories. With the silencers, two main parameters should be taken care of: the first one is sound attenuation and the second one is pressure losses. In the presented paper, the focus is on measurement methods described by standard ISO 7235:2009. This standard specifies the methods for determining the sound power level of the flow noise generated by silencers, the total pressure of silencers and the insertion loss of silencers with and without airflow by using the substitute object. In this work, we focused on the correlation between the shape of the substitution duct and its acoustic parameters and its relation to this with the final result of insertion loss of a silencer.

Keywords: silencer, insertion loss, aeroacoustic.

1. Introduction

HVAC systems, by the sound of air moving through ducts and other elements, can produce a lot of unwanted noise, which usually needs to be attenuated. Controlling HVAC noise is vital because the continuous or intermittent noise from an HVAC system can be distracting as well as disruptive [1]. In such systems, there are practical and economical solutions to these problems, like using absorbing material, extending the length of the ducts and adding plenums or silencers [2]. Silencers (another term - attenuators, absorbers or mufflers) to reduce the noise transmitted from a source to a receiver are designed, for example, from fans through ducts to the grilles or exhaust air vent elements. Airflow noise attenuation in ducts becomes of major interest to the acoustic comfort of the users of residential or commercial buildings. Two types of silencers are used to attenuate sound: reactive and dissipative. Reactive mufflers reduce sound through resonances and anti-resonance determined by their geometrical shape, like expanded chambers along a duct of the silencer. Dissipative silencers attenuate sound mainly through the presence of sound-absorbing materials with a certain flow resistivity [3]. For these two types of silencers, the acoustic performance is generally described in terms of "insertion loss". Insertion loss is a term used to describe the difference in sound pressure level before and after incorporating a change to a given system. It is used to gauge the impact of sound-reducing by the HVAC elements.

Laboratory measurements by using the substitution procedure to determine the insertion loss of silencers of all kinds and other devices in flow ducts are described in the European Standards EN ISO 7235 [4], EN ISO 11691 [5] and EN ISO 5135 [6] and also in the American Standard ASTM E477 [7]. In these standards the experimental measurement procedures to determine the insertion loss in frequency bands of ducted silencers and air-terminal units with and without airflow.

EN ISO 11691 standard describes a laboratory survey method using a substitution procedure to determine the insertion loss of ducted silencers without the airflow. This standard offers an established and standardized method for measuring transmission loss of silencers and other duct elements used in ventilation by using the sound source, test piece and the receiving end for example the reverberation room or free field over one or more reflecting planes. EN ISO 5135 guidance relates to the determination of sound power levels from ventilation system elements measured within the reverberation room with and without the studied elements.

ASTM E477 and EN ISO 7235 standards test methods (very similar) are often used for measuring the acoustical performance of silencers. The popularity of ASTM E477 standard has been proven by finding it as a reference in many published articles and also in the ASHRAE's HVAC Application Handbook [8]. EN ISO

7235 determine the insertion loss of silencers of all kinds and other devices in flow ducts and is popular in European laboratories. This standard describes laboratory measurement procedures for attaining insertion loss, flow noise and pressure loss for silencers and other air-terminal units using the substitution method. Measurements of the pressure loss and flow noise are determined by the suitable configuration of the source and receiver sides test stand. The determination of flow noise from a silencer requires a much higher effort than the measurement of insertion loss without flow. It includes substantial attenuation of the fan noise, appropriate guidance of the flow at the receiver side, corrections for the reflection at the duct exit and the potential influence of the reverberation room. Very effective silencers must be inserted between the fan and the silencer under test. The exit duct cross-sectional area must be substantially larger than the free cross-sectional area in the silencer [9]. The test silencer and substitution duct must have similar acoustic properties.

But there are ambiguities in the EN ISO 7235 standard, regarding how it should look like the substitution duct. Point 5.2.3 standard says, that as a substitution duct the empty housing of the test silencer could be used. But if it is not possible to use the empty housing of the test silencer, the substitution duct shall be matched in size and shape to its inlet and outlet. That is a good approach for the square silencer, where there are attenuation panels mounted by inserting into the housing. But in the case of a rounded silencer, the shape of the substitution duct is important for insertion loss parameters. In this work we focus on the studied insertion loss of rounded silencers with three inlet diameters of 80 mm; 250 mm and 315 mm with two thicknesses of wool - 50 mm and 100mm. As a substitution duct, the housing of studied silencers without the wool layers with compare to the straight duct was used. Important, for engineers and architects, a parameter for studied silencers is insertion loss, which was determined and compared depending on the using substitution duct.

2. Test objects

The test objects were round absorption silencers with connection diameters (d) 80 mm, 250 and 315 mm. The silencer with an inlet diameter of 80 mm had a length (L) of 300 m, and the remaining silencers had 600 mm. Each of the objects had an absorbing material (mineral wool) with a thickness (H) of 50 and 100 mm. Additionally, a silencer with a 250 mm inlet diameter and 900 mm length and with a different type of 50 mm mineral wool was used to compare the correlation between the length parameter and insertion loss.

The above-mentioned empty silencers cases (without absorbing material and perforated sheet inside) and straight ducts with the same diameter and the same length as the silencer connection were used as substitution ducts.

All dimensions of the silencers are listed in Table 1.

Table 1. Dimensions of the tested silencers in millimetres.

d	D	H	L
80	180	50	300
	280	100	300
250	350	50	900
	350	50	600
	450	100	600
315	415	50	600
	515	100	600

Figure 1 shows the cross-sections of silencer and silencer empty casing with dimension designations.

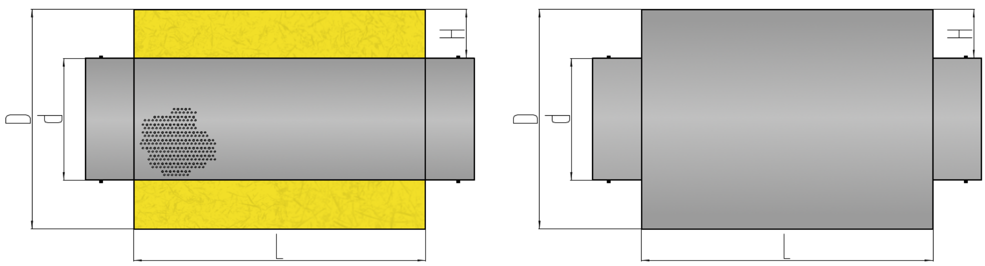

Figure 1. Cross section of silencer and silencer empty case.

3. Experiment

We made the measurements on a test stand built following the norm PN-EN ISO 7235:2009 "Acoustics - Laboratory measurement procedures for ducted silencers and air-terminal units - Insertion loss, flow noise and total pressure loss" [4]. The reverberation room has a volume of 237.0 m^3 and an area of 231.5 m^2 with non-parallel walls. We connected the tested object to the centrifugal fan through three absorption silencers and a noise source outside the chamber, as shown in Figure 2.

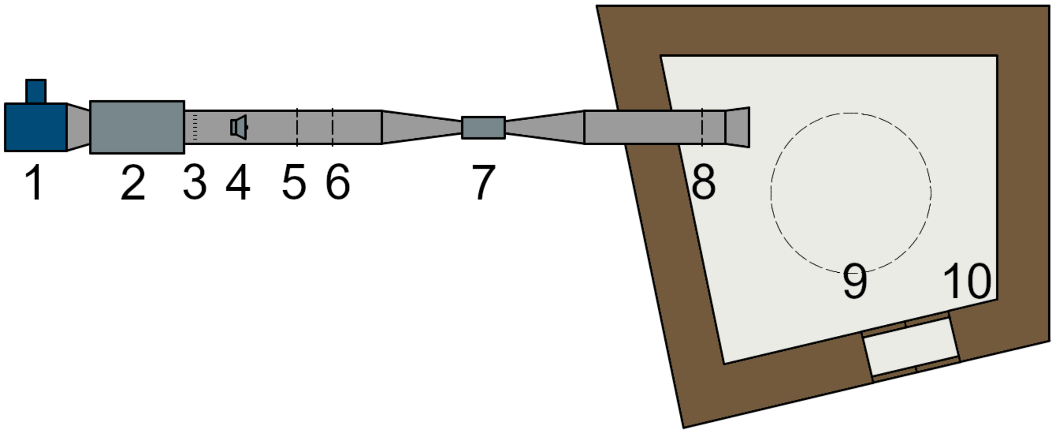

Figure 2. Test stand with a reverberation room scheme: 1) fan, 2) set of three silencers, 3) flow straightener, 4) noise source, 5) pressure and temperature measurement, 6) flow velocity measurement, 7) test object, 8) pressure measurement, 9) microphone path, 10) reverberation room.

The tests with the pink noise source turned on for four flow velocities of 3, 6, 9 and 12 m/s at the inlet of the tested object were carried out. We set the volumetric flow by changing the rotation frequency of the fan motor by using a three-phase inverter connected with the motor. Flow velocity using the Prandtl Tube according to norm PN-ISO 5221:1994 "Air distribution and air diffusion - Rules to methods of measuring air flow rate in an air handling duct" [10] was measured. The static pressure drop on the tested silencer was measured in through and behind the silencer at four evenly located points around the channel. A differential electronic pressure transducer for this was used.

The generated noise is determined by sound power level, measured according to PN-EN ISO 3741:2011 "Acoustics - Determination of sound power levels and acoustic energy levels of noise sources based on sound pressure measurements - Precision methods in reverberation chambers" [11]. The Brüel&Kjær 2144 measuring set with the Brüel&Kjær 3923 rotary table for the measurements was used. The sound pressure at nine points in a circle with a radius of 1.7 meters (circumference of 10.7 m) was measured. Measured in 1/3 octaves in the range from 100 Hz to 10,000 Hz. The measurement time was set to 30 seconds. Background noise was measured for a stand without flow to determine the background correction K_1. Reverberation for four omnidirectional loudspeaker settings with three microphone settings was measured also. Before and after all measurements, we use the Brüel&Kjær 4231 calibrator. After measuring each setting, the temperature, relative humidity and atmospheric pressure necessary for calculating the sound power were recorded.

4. Results

Insertion loss was used to present the results. Insertion loss D_i is a reduction in the level of the sound power in the duct behind the test object due to the insertion of the test object into the duct in place of a substitution duct, given by the equation (1):

$$D_i = L_{\mathrm{WII}} - L_{WI} \tag{1}$$

where:

- L_{WI} - the level of the sound power in the frequency band considered, propagating along the test duct or radiating into the connected reverberation room when the test object is installed;
- L_{WII} - the level of the sound power in the frequency band considered, propagating along the test duct or radiating into the connected reverberation room when the substitution duct replaces the test object.

Because the sound power level does not depend on the airflow velocity, average values are used in the calculations.

Table 2 contains the results of the insertion loss calculation for a single A-weighted value sound power level.

Table 2. Insertion loss D_{iA} for single A-weighted value sound power level.

inlet diameter		80 mm		250 mm		315 mm	
wool thickness		50 mm	100 mm	50 mm	100 mm	50 mm	100 mm
substitution duct	silencer case	10.2 dB	6.6 dB	9.5 dB	11.4 dB	8.7 dB	7.5 dB
	straight channel	19.0 dB	18.0 dB	12.9 dB	16.7 dB	12.1 dB	12.9 dB
difference		8.8 dB	11.4 dB	3.4 dB	5.3 dB	3.4 dB	5.4 dB

In Figure 3, we see the insertion loss spectrum of silencers with an 80 mm diameter inlet and 50 and 100 mm thick absorbent material. As a substitution duct, an empty silencer case and a straight pipe were used. In Figure 4 and Figure 5, the results for silencers with an inlet diameter of 250 and 315 mm were presented.

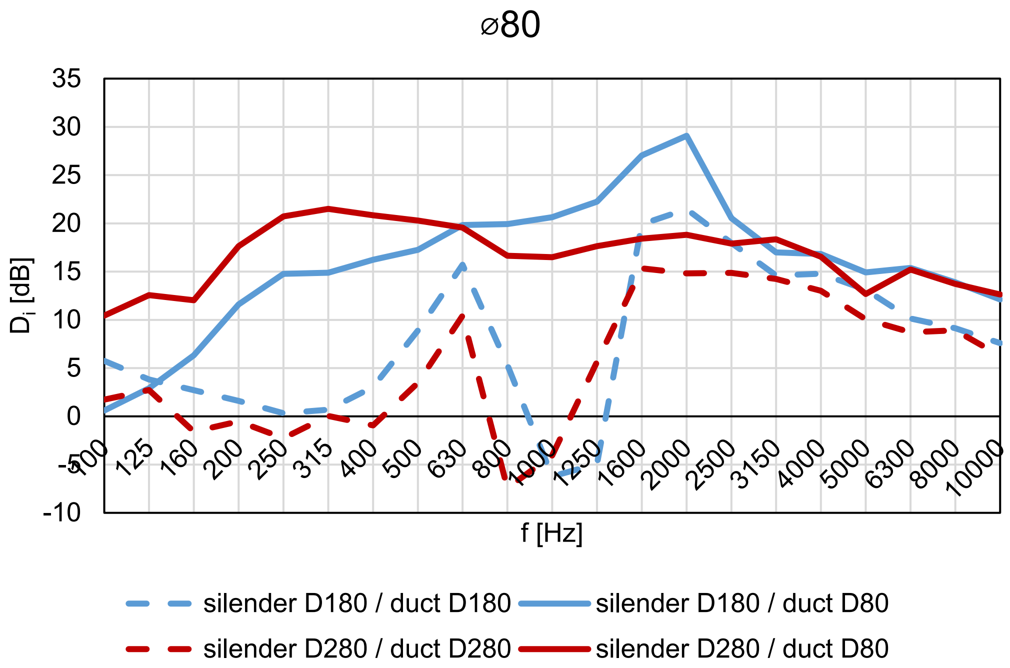

Figure 3. Insertion loss for silencers with 80 mm diameter inlet and outlet. The blue line - silencer with 50 mm wool; the red line - silencer with 100 mm wool. The solid line marked the insertion loss compared to the straight channel, and the dashed line to the empty silencer case.

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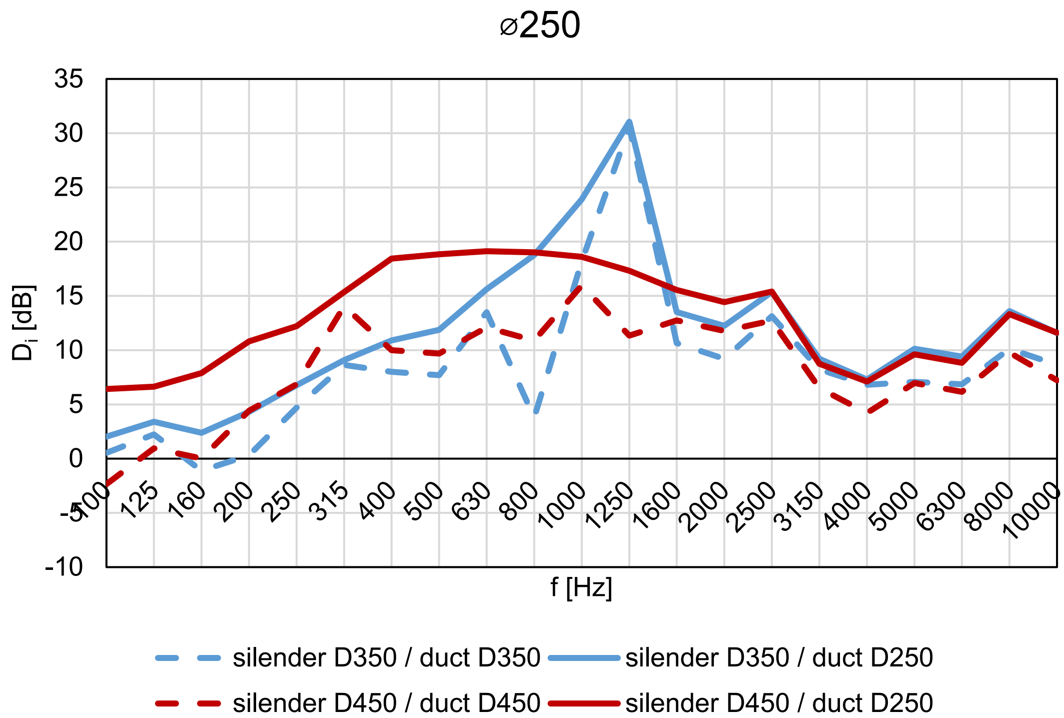

Figure 4. Insertion loss for silencers with 250 mm diameter connection. The blue line - silencer with 50 mm wool; the red line - silencer with 100 mm wool. The solid line marked the insertion loss compared to the straight channel and the dashed line to the empty silencer case.

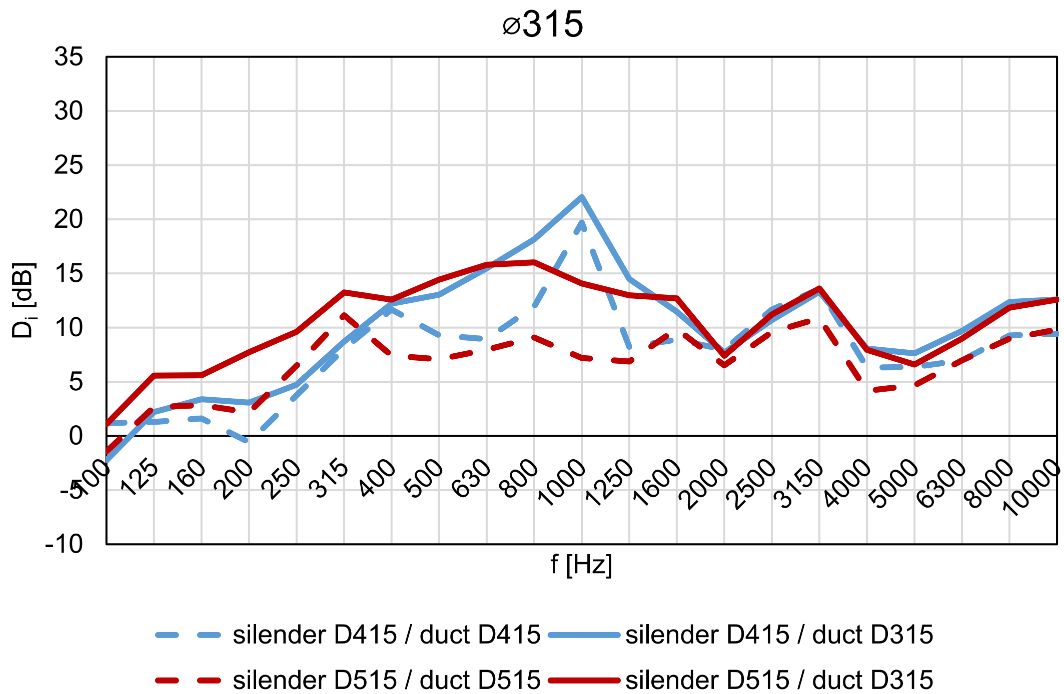

Figure 5. Insertion loss for silencers with 315 mm diameter connection. The blue line - silencer with 50 mm wool; the red line - silencer with 100 mm wool. The solid line marked the insertion loss compared to the straight channel and the dashed line to the empty silencer case.

In Figure 6, we see the insertion loss spectrum of empty silencers case with an inlet diameter of 80 mm. A straight channel as a substitution duct was used. In Figure 7 and Figure 8, the results for cases with an inlet diameter of 250 mm and 315 mm properly is presented.

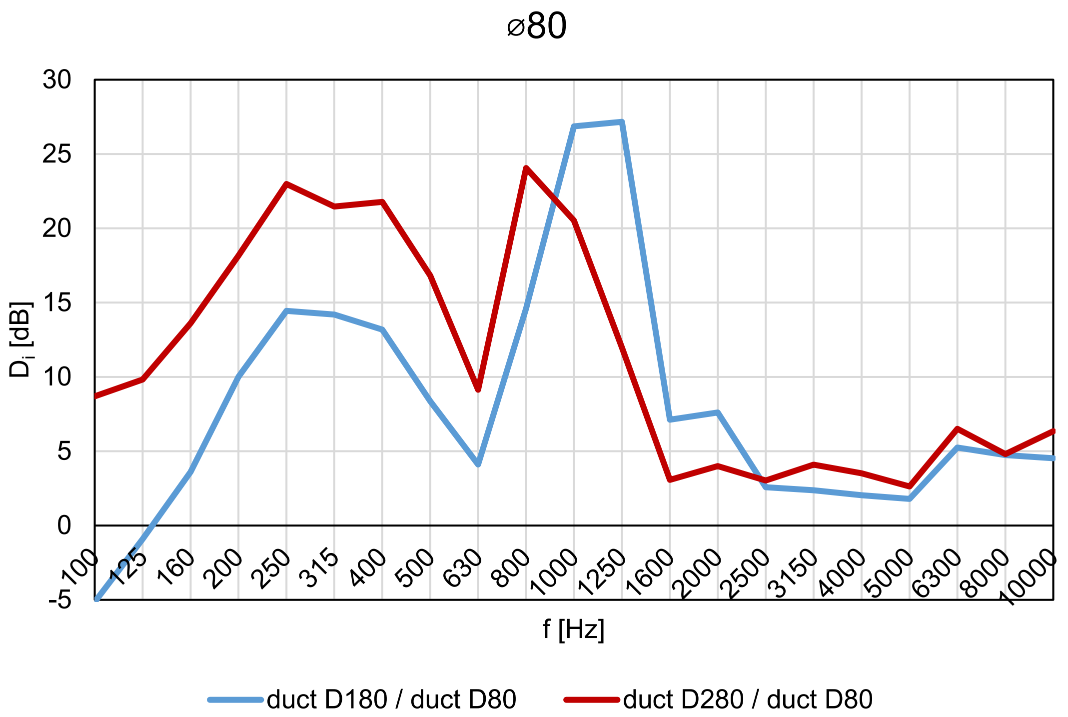

Figure 6. Insertion loss for empty silencers case compared to the straight channel with 80 mm diameter connection. The blue line - silencer with 50 mm wool and the red line - silencer with 100 mm wool.

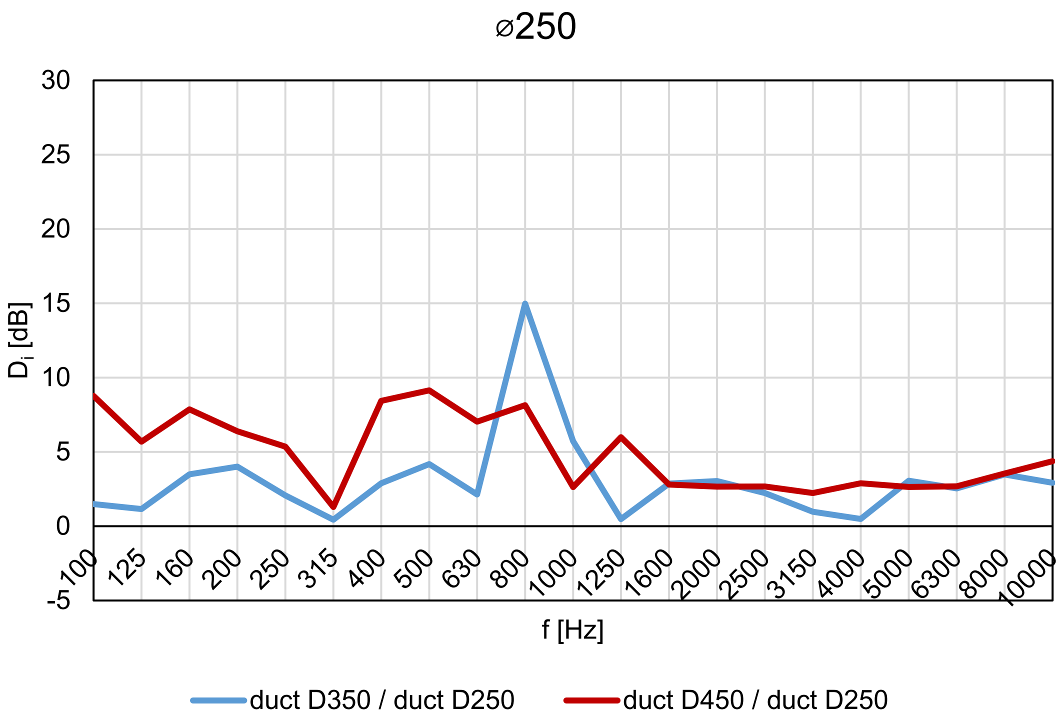

Figure 7. Insertion loss for empty silencers case compared to the straight channel with 250 mm diameter connection. The blue line - silencer with 50 mm wool and the red line - silencer with 100 mm wool.

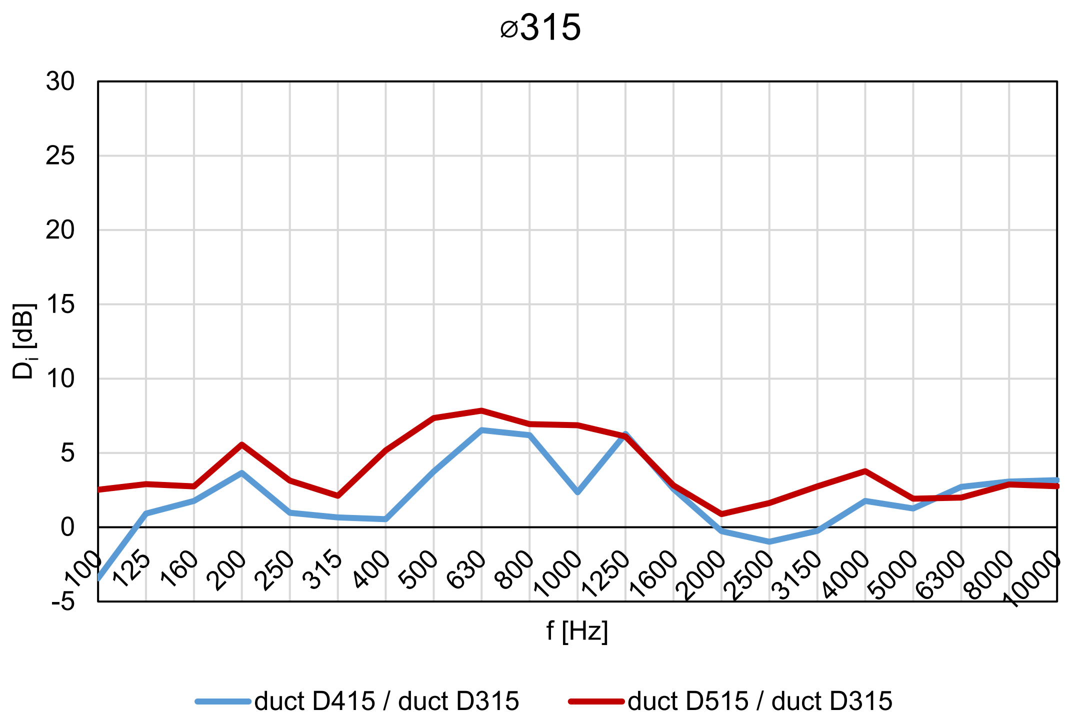

Figure 8. Insertion loss for empty silencers case compared to the straight channel with 315 mm diameter connection. The blue line - silencer with 50 mm wool and the red line - silencer with 100 mm wool.

In Figure 9, the spectrum of the sound power level for an empty silencer case with 600 mm and 900 mm lengths is presented. Both enclosures have a 250 mm inlet and space for 50 mm thick of the absorbent material. The result of insertion loss was not presented because the two silencers had different absorbing materials. The only significant difference is the lower sound power level for a shorter silencer (600 mm) at a frequency of 800 Hz. This frequency is close to the acoustic wavelength equal to the cross-section diameter of the empty silencer casing.

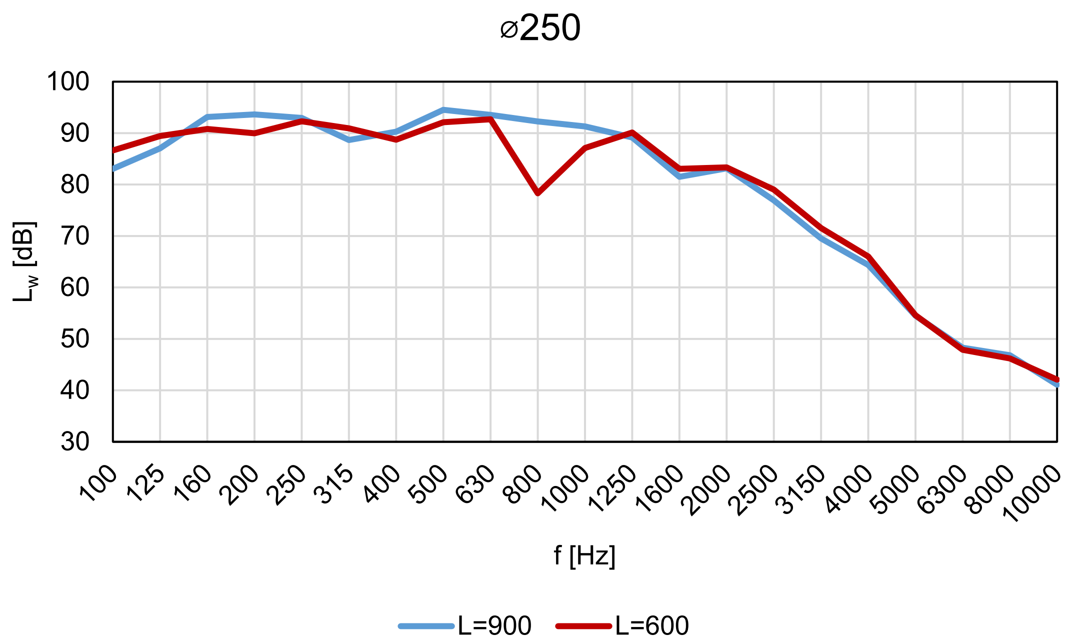

Figure 9. The sound power level for an empty case of ϕ 250mm silencer with 50mm space for the absorbent material with a length of 900 mm (blue line) and 600 mm (red line).

5. Conclusions

In this paper, the insertion loss of silencers with 80-315 inlet diameter and with 50 mm and 100 mm wool thickness were studied by using two types of substitution duct, according to the EN ISO 7235 standard. We found differences between the insertion loss of the studied silencer depending on the using substitution ducts. The current EN ISO 7235:2009 standard does not exactly specify the parameters of substitution duct. This can cause an ambiguous understanding of the laboratory measurements procedure and affect the silencer insertion loss.

The standard requires is the use of a substitution duct the same as the silencer but without the attenuation material. For the silencer with an 80 mm inlet diameter, the shape of the substitution duct has a strong influence on the insertion loss by decreasing this parameter. At some frequencies, the insertion loss as a negative value (see Figure 3) was measured. This effect diminishes with increasing the diameter of the silencer, but even for a silencer with a 315 mm inlet diameter, we observe the influence shape of the substitution duct on the insertion loss parameters.

If such duct (like a silencer without the wool) will be used during the measurements, strong acoustic resonances could be observed. For an 80 mm inlet diameter silencer with 50 mm wool thickness, two peaks are observed at 630 Hz and 2000 Hz, when the substitution duct with accurate silencer shape was used. These peaks decreased when the thicker wool in the silencer was used. In the case of the 250 mm silencer one peak at 1250 Hz was observed and for the 315 mm silencer only a peak at 1000 Hz. Also, decreased these peaks were observed when the thicker wool was used.

These resonances are created by the repeated internal reflection of sound at the substitution ducts which react as a plenum box. The location and spacing of these resonances will depend on the diameter and overall length of the substitution duct. An empty silencer case also works as a silencer in the wide frequency range. Problems with empty duct resonances can be avoided entirely by eliminating the empty duct portion of the test and replacing it with a calibrated reference silencer or by using the straight duct.

Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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