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Design of the Test Facility for the Measurement of noise Silencers

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Abstract In the paper, a description of the test facility designed and implemented for noise silencers according to the methodology specified in the PN-EN ISO 7235 standard is presented. It is possible to measure the insertion loss, flow noise, and pressure loss on the test stand. In particular, the following issues were presented: noise protection in the low frequency range, the design of the anechoic termination, and measurements of the sound pressure level in the flow. To obtain a sufficiently high level of noise protection, three noise transmission paths were considered: direct, indirect, and flanking. The design of the anechoic termination was based on the profile of the catenoid tube, which made it possible to obtain strong sound absorption in the low-frequency range while maintaining a limited length of a terminator. A specially designed microphone cap was used to measure the sound pressure level in the flow field. The paper also presents results of selected measurements that illustrate the possibilities of the designed test stand.

Keywords: baffle silencers, insertion loss, flow noise.

1. Introduction

The acoustic parameters of the noise silencers can be determined either by calculation or measurement. The results obtained by the calculation methods, which are convenient because of their ease of application at the design stage, unfortunately differ significantly in many cases from the parameters obtained in practice. This is particularly the case for the calculation of baffle silencers, since the final parameters of such silencers strongly depend on the precision of their manufacture and on the design solutions used. Therefore, every designer of noise protection for technical installations, e.g. mechanical ventilation, prefers attenuation data obtained through measurements, in particular with regard to insertion attenuation and flow noise. Consequently, every manufacturer of acoustic attenuators strives to provide data obtained in measurement laboratories in its product catalogues and, in many cases, the lack of such information negatively affects its position in the market. However, this is understandable, since the determination of the acoustic parameters of noise silencers, according to the existing international standard EN ISO 7235 [1], requires the use of a rather complex and, in particular, large measurement system (generally more than 20 m in length).

The existing international standard EN ISO 7235 [1] specifies in detail the design and parameters of a measuring system for measuring acoustic parameters of silencers and installation fittings. The most important parameters of such elements are: insertion loss, flow noise, and static pressure drop across the element. These parameters are measured in a system with a defined air flow in the elements under test. The exception is insertion loss, which can be measured in a system with or without flow, and the results obtained should be comparable, according to EN ISO 7235 [1].

A test system for measurements with flow is considerably more complicated than one without flow and imposes a number of additional requirements that necessitate the use of complex and expensive design solutions. Among other things, such a system for insertion loss measurements requires a specialised reverberation chamber or an acoustic anechoic termination with the provision of airflow in a closed ventilation system.

This article presents a description of a test system for measuring components of a ventilation system with and without flow, designed and realised for a ventilation and air-conditioning company in Rzeszów.

2. Measurement set-up

The measurement system allows the measurement of insertion loss, flow noise, and pressure loss on components of a ventilation system with air flow of up to 20 m/s in the component under test.

It is possible to measure insertion loss at least up to the value specified in Tab.1.

Table 1. Maximum insertion loss available to measure at the test facility in octave bands.

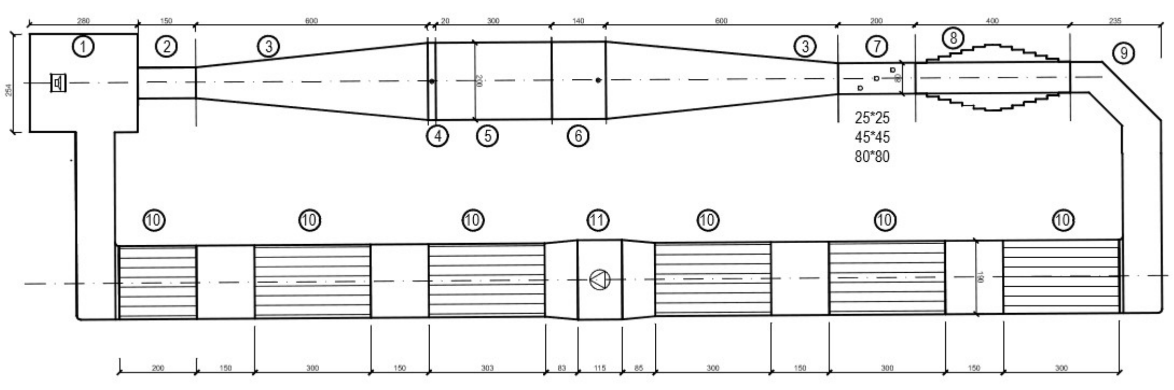
f [Hz]	63	125	250	500	1000	2000	4000	8000
ΔL [dB]	15	30	50	50	50	50	50	50

The system consists of the following main components (see Fig. 1): sound source in the expansion chamber (1), modal filter (2), transition ducts (3), ducts for pressure drop measurements (4, 6), test duct where sound power is measured (7), anechoic termination (8), baffle silencers in supply and extract path (10), fans supply the flow up to 24000 m^3 /h (11).

Fig. 1 shows the dimensions of the individual components of the measuring system. In order to be able to carry out measurements within the assumed range of attenuator/shape dimensions, the measuring system is realized by means of three interchangeable branches with different cross-sections (the upper branch in Fig. 1), i.e. the measuring branch and a fixed lower branch. The interchangeable branch starts at the element (2) (modal filter) and ends at the two elbows (9). The upper exchangeable branch is needed to carry out measurements of: small fittings with a cross-section of 0.25×0.25 m; medium fittings with a cross-section of 0.45×0.45 m; and large fittings and baffle silencers, with a cross-section > 0.80×0.80 m.

Three ½" microphones connected to a four-channel sound level meter were placed in the measurement duct (7). The microphones were additionally fitted with a slotted probe designed to measure noise levels under increased airflow conditions, terminating in a G.R.A.S RA0020 protective cone designed to be mounted on a 1/2" microphone. The air flow velocity in the measuring duct was recorded using a Testo 400 multifunction meter (flow velocity, temperature, and humidity are measured using an external probe, while the differential pressure measurement function is built into the meter). The air velocity between the baffles was determined from the measured flow velocity in the measuring duct . A JBL PRX 815 loudspeaker set placed in the acoustically damped chamber (1) was used as the sound source.

The lower branch consists of three fans connected in parallel with a maximum capacity of up to 24,000 m^3/h and six baffle attenuators (10). The maximum linear air velocity in the lower branch is less/equal to 7 m/s. The overall dimensions of the measurement system are 29.2m (length), 7.4m (width), and 2.1m (height).



1 – loudspeaker in sound chamber;
2 – modal filter,
3 – transitions,
4, 6 – ducts for pressure drop measurements,
5 – silencer under test,
7 – test duct,
8 – anechoic termination,
9 – duct bends,
10 – baffle silencers in supply and extract path,
11 – fans.

Figure 1. Measurement set-up (dimension in cm).

3. Noise protection

The main noise sources in the test duct are listed below.

1. Domestic noise arising from other floors of the building. This noise was mitigated by enclosing the measurement duct with an additional external sheet steel jacket. In this way, the duct walls formed a double wall construction.
2. Noise from supply fans, which propagated via a direct route through the ducts and an indirect route through the building. Disturbance on the direct route was reduced by using three sections of noise attenuation in the supply and extract ducts, while on the indirect route by placing fans and silencers in three separate rooms (areas A, B, and C in Fig. 2).
3. Sound sources in the sound chamber in the indirect path when measuring insertion loss.

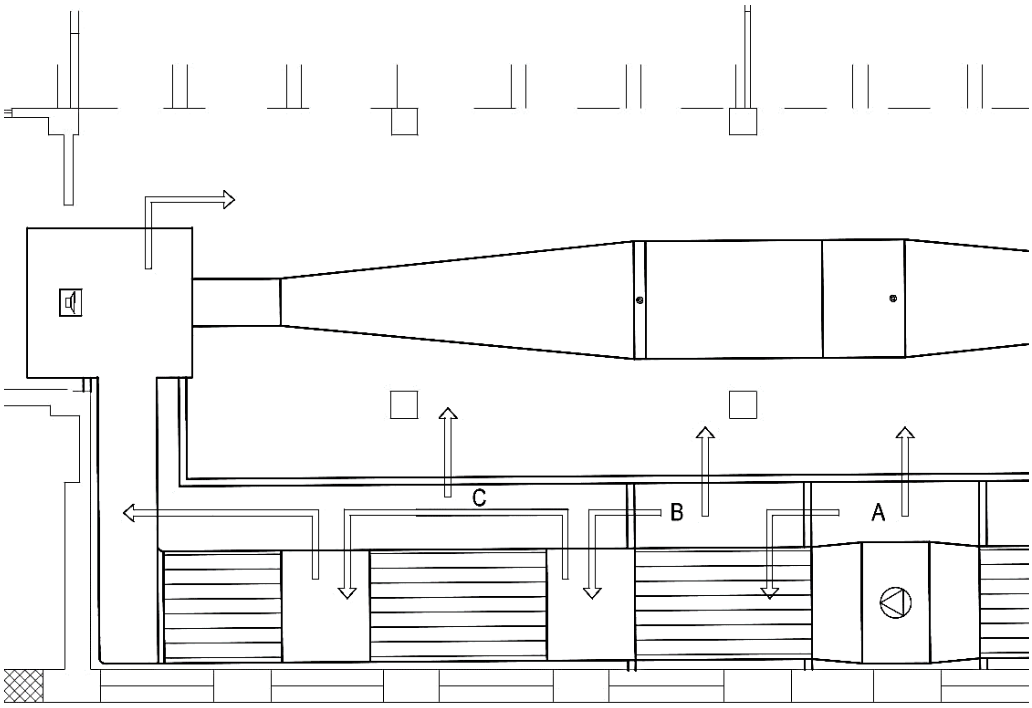


Figure 2. Indirect paths of noise transmission in the supply section.

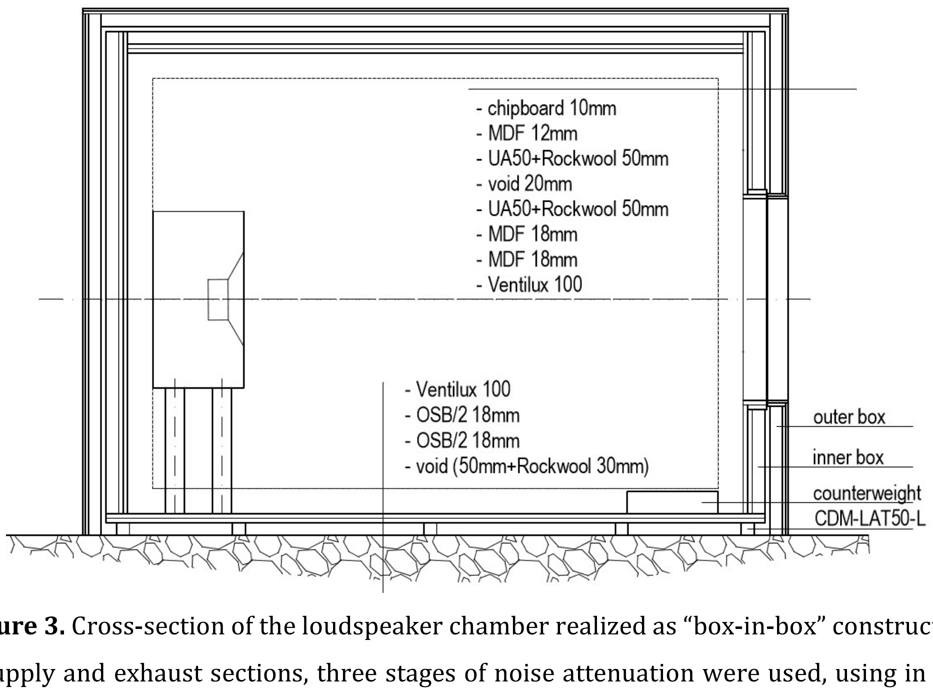


Figure 3. Cross-section of the loudspeaker chamber realized as "box-in-box" construction.

In the supply and exhaust sections, three stages of noise attenuation were used, using in each stage a baffle silencer with appropriate attenuation and controlled flow noise in each stage. In addition, noise that transmitted through the walls and the walls of the silencers themselves was also taken into account in the calculations. The most difficult part was to achieve sufficiently low noise in the test duct (7, Fig. 1) in the low frequency range.

In addition, to be able to measure the assumed insertion loss in the low-frequency range (15 dB, Tab.1) with at least 10 dB above the background, it was necessary to ensure acoustic isolation of at least 35 dB in the low-frequency range on the indirect and flanking path: expansion chamber - test duct. For this purpose, the chamber was constructed as a „box-in-box" design (Fig. 3), where vibration isolation of the inner box was used to limit flanking transmission.

To determine the acoustic conditions in the test duct (7, Fig. 1), including the acoustic background, several measurements were carried out for different operating configurations of air handling units.

- 3 fans switched off;
- 3 fans operating at the nominal operating point: two small ones with a capacity of 6,000 m^3/h each and one large one with a capacity of 12,000 m^3/h (2+1). A flow rate of 10.0 m/s was obtained in the test duct with a cross-section of 0.80×0.80 m;
- 2 small units at nominal operating point, large unit off (2+0). A flow rate of 5.7 m/s was obtained in a test duct with a cross-section of 0.80×0.80 m;
- 1 small fan at nominal operating point, other units off (1+0). A flow rate of 3.0 m/s was obtained in the test duct with a cross-section of 0.80×0.80 m;
- 1 large fan at nominal operating point, other units off (0+1). A flow rate of 6.0 m/s was obtained in the test duct with a cross-section of 0.80×0.80 m.

The results of the measurements are shown in Fig. 4.

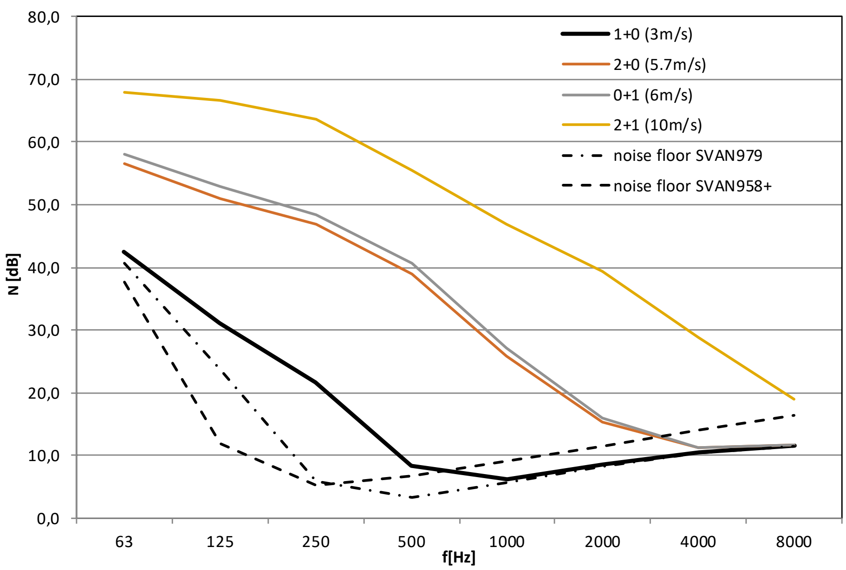


Figure 4. Noise in the test duct at different work points of fans as compared to the noise floor measured by two different sound meters.

Based on the measurements carried out and the results presented, the following conclusions can be drawn:

- above 500 Hz, the acoustic background in the test duct is determined by the self noise of the meters used;
- in the range below 250 Hz, the acoustic background in the test duct is defined by the noise from the air handling units. The exception is the 63 Hz octave, where the acoustic background is derived from domestic noise present in the building;
- due to the doubling of the air flow velocity from 3 m/s to 6 m/s when moving from one small fan to two small units, the increase in noise in the test duct in the low and medium frequency range is between 8 dB and 18 dB. This means that the noise measured for one small fan is flow-noise nature and is not fans noise. Otherwise, a noise increase of 3 dB would be observed (energy sum for two of the same air handling units). This confirms the sufficient effectiveness of the noise silencers used in the lower branch of the measurement system;

- flow noise measurements in the two highest octaves (4,000 Hz and 8,000 Hz) at low air velocities in the test duct, i.e. below about 8 m/s, will be subject to error due to the self noise of the measuring equipment used.

4. Anechoic termination

The anechoic termination was made in such a way as to provide the required low reflection of sound and to allow airflow. The termination consists of three sections: an expanding catenoid, a fixed cross-section, and a tapering catenoid. The centre of the square-shaped fixed-section waveguide allows the medium to flow freely. The catenoid cross-section shape has the best properties: for given inlet, outlet, and length dimensions, this shape ensures the lowest cut-off frequency and acoustic impedance matching above the cut-off frequency.

The catenoid shape of the termination in the direction of wave transmission is given by the following dependence of the cross-sectional area on the distance *x* from the inlet:

$$S(x) = S_0 \cosh^2\left(\frac{mx}{2}\right) \tag{1}$$

where m – is the form factor. The form factor determines the cut-off frequency:

$$f_{gr} = \frac{mc}{4\pi} \tag{2}$$

where c is the speed of sound, in air c=343 m/s. For the catenoid tube, the matching takes place immediately above the cut-off frequency. The cross-sectional area of the anechoic termination consists of two parts: a square waveguide with a side a, through which the medium can flow, and a catenoidal part placed along one, two, or four sides of the waveguide. The side of the waveguide to which the catenoid part is adjacent is perforated with a perforation ratio of 55 ÷ 60%. The interior of the catenoid part is filled with a sound-absorbing material: glass wool with a density of 20÷40 kg/m^3. The side walls of the catenoid part are an extension of the corresponding side of the waveguide. The cross-sectional area of the waveguide, given by equation (1), can be represented as follows:

$$S(x) = a^2 + n \cdot a \cdot h(x) \tag{3}$$

where: n = 1, 2 or 4, $h(x)$ – external profile of the catenoid part. By comparing (1) and (3), the shape of the catenoid profile is obtained:

$$h(x) = \frac{a}{n}\left[\cosh^2\left(\frac{mx}{2}\right) - 1\right] \tag{4}$$

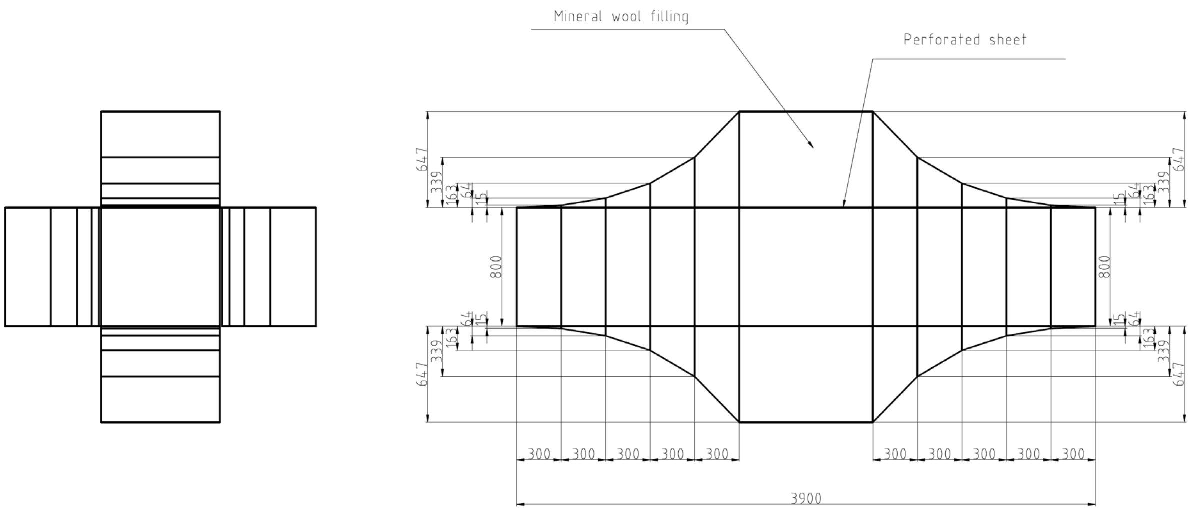


Figure 5. Anechoic termination with a square clearance cross-section 0.80×0.80 m.

The calculations were carried out for a cut-off frequency of 50 Hz and for three cross-sectional sides: a = 0.25 m, 0.45 m and 0.80 m. For a pipe with a side a = 0.25 m, n = 2 was adopted (the catenoid part is placed on two opposite walls of the waveguide), while for a waveguide with a side a = 0.80 m, n = 4 was adopted (the catenoid part is placed on all four walls of the waveguide). For the intermediate case $a = 0.45$ m, calculations were carried out for two variants: $n = 2$ and $n = 4$. Based on formula (2), the form factor $m = 1.8$ m^{-1} was determined. The calculation of $h(x)$ was carried out in increments of 0.30 m from $x = 0$ to 1.5 m, then the cross-section is constant up to a value of $x = 2.4$ m, after which it decreases symmetrically to $x = 3.9$ m (Fig. 5, [3]).

The anechoic termination according to EN ISO 7235, Chapter 5.2.4.3 [1] should be characterised by acoustic pressure reflection coefficient $r_R \leq 0.30$. When converted to the energy absorption coefficient α, this condition means a value $\alpha > 0.91$. Fig. 6 [3] shows the result of a measurement of the sound absorption coefficient of an anechoic termination with a side of 0.80 m. Measurement was carried out in the constructed stand (Fig. 1) according to EN ISO 10534-2 [4].

It can be seen on Fig. 6 the condition $r_R \leq 0.3$ / $\alpha \geq 0.91$ is fulfilled for thirds from 50 Hz, so the designed anechoic termination meets the requirements of EN ISO 7235 [1].

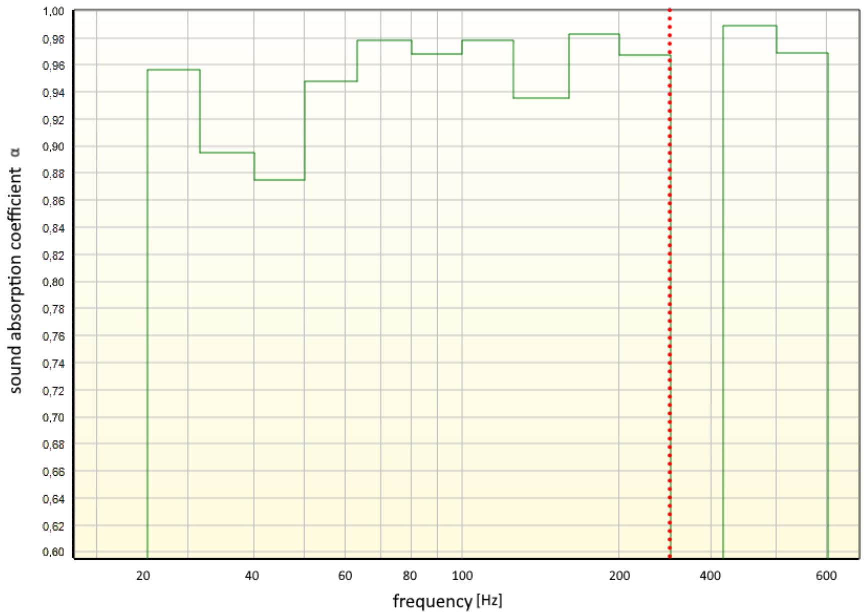


Figure 6. Measured sound absorption coefficient a of anechoic termination with a square cross-section 0.80×0.80 m.

5. Flow noise

In order to obtain reliable noise measurements in the test duct for system with air flow, the turbulences occurring on the diaphragm of the measuring microphones must be reduced. For this purpose, suitable microphone covers, e.g. in the form of so-called nosecones or specially designed measurement probes, should be used. Several solutions listed in EN ISO 5136 [2] compared them with the commercially available GRAS nose cone. It was shown that the use of a measuring probe based on the design specified in EN ISO 5136, Annex G [2] and with the use of a suitable probe-tube shielding fabric (Fig. 7), it is possible to reduce flow noise at the microphone diaphragm by 5 to 10 dB compared to a commercial nosecone (Fig. 8). The tests were carried out for a flow rate of 10 m/s, which is the maximum flow rate in the 80×80 cm test duct for the air handling units used.

Figure 7. Measurement nosecone with the suitable probe-tube shielding mounted on the measurement microphone.

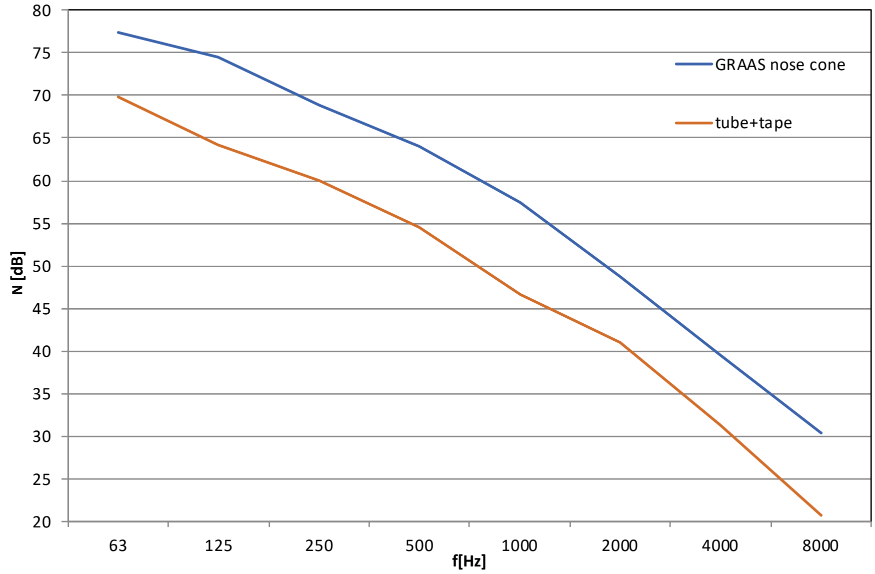


Figure 8. Flow noise of the commercial nose cone and of the measurement probe according to PN-EN ISO 5136 [2] for laminar flow at a velocity 10 m/s.

6. Results of the measurements

The figures below show the measurement results of the insertion loss and flow noise of two selected silencers: a 1 m and a 2 m long silencer, constructed with 200 mm thick baffles and A2-BLACK material (compressed glass wool protected with fleece). The insertion attenuation (Fig. 9) was measured without flow at different baffles spacings: from 60 mm (30% silencer clearance) to 200 mm (50% clearance). The flow noise shown in Fig. 10 was measured for 10 different air velocities between the baffles: from 4 m/s to 20 m/s. The flow rate was calculated based on velocity measurement at the end of test duct (7 in Fig.1).
From the measurement results for the 2 m attenuator it can be seen that in the range above 500 Hz it was possible to measure attenuation of more than 50 dB (even up to 70 dB), while for the lowest octave of 63 Hz a maximum attenuation of 11 dB was obtained. The values obtained for tested silencers are close to those obtained theoretically.

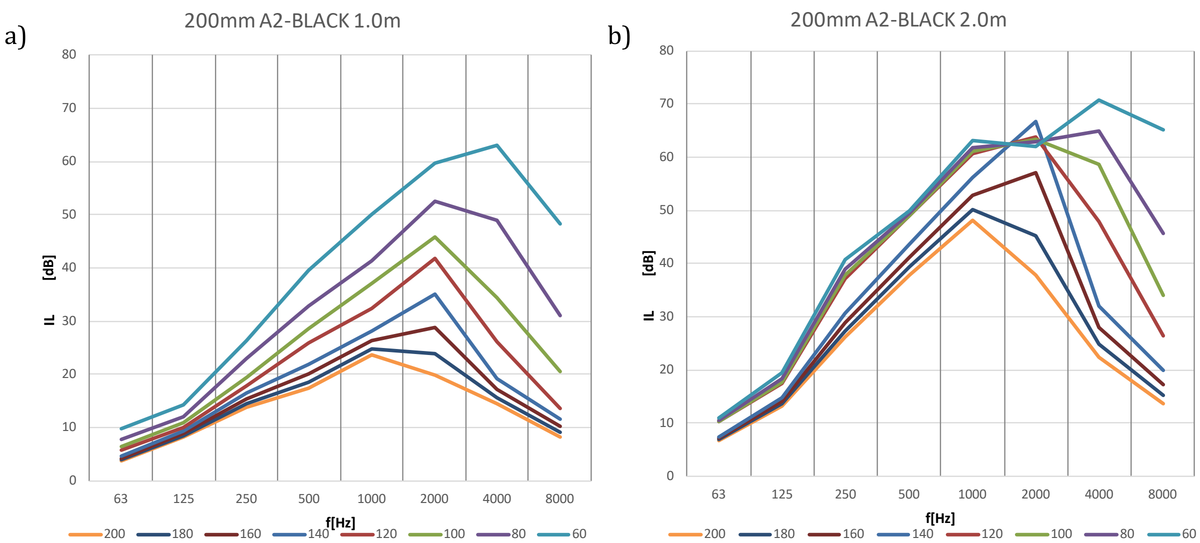


Figure 9. Insertion loss of baffle silencers of length: a) 1m and b) 2 m, built up using 200 mm width baffles spacing from 60 mm to 200 mm.

When comparing the results for silencers of different lengths, it can also be observed that, as a result of doubling its length, the attenuation, according to theory, approximately doubles. This is particularly noticeable for attenuators with a large baffles spacing.

The measured flow noise spectrum, in accordance with theory, has a brown noise character (6 dB drop per frequency doubling). The results also illustrate the limitations occurring at high frequencies due to the inherent noise of the sound level meter used. Moreover data obtained at 4 m/s in Fig.10 is doubtful and probably show of the flow noise of the stand with the substitute duct. Full-band measurement is only possible at air velocities of more than 10 m/s between the baffles. In the low- and medium-frequency range, correct measurement of flow noise on the developed test set-up is possible from 6 m/s onward.

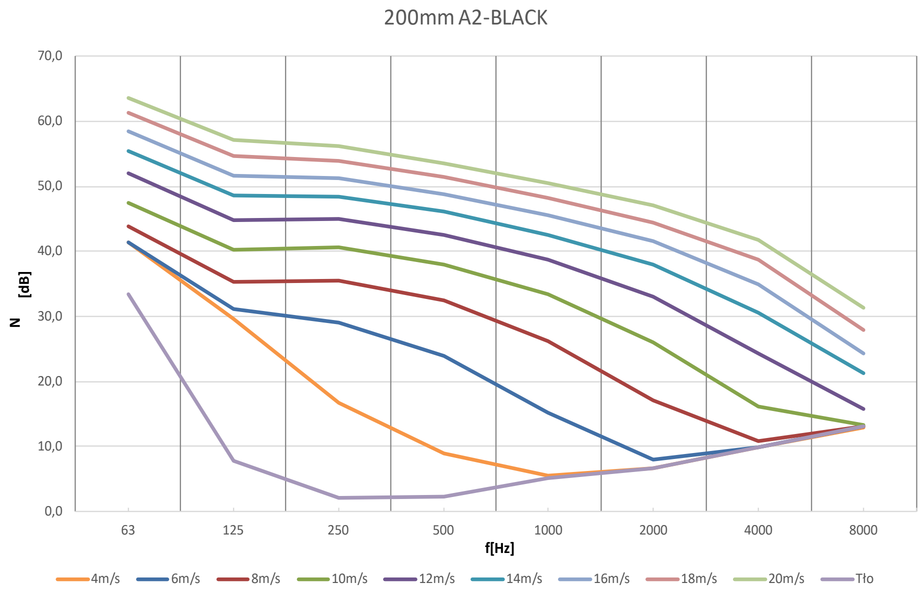


Figure 10. Flow noise of baffle silencers builts up using 200 mm width baffles.

7. Conclusions

This article presents the design of a test facility to measure the attenuation of ventilation elements and baffle silencers according to EN ISO 7235 [1]. In particular, the issue of noise protection of the set-up, the design of the catenoidal anechoic termination, and the problems of noise measurements in the flow field are discussed. Selected results of measurements of baffle silencers on the realised stand are given, and its acoustic properties and limitations resulting from the design assumptions made and the measurement apparatus used are discussed.

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. This paper has been supported by European Regional Development Fund.

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