VPS VIBRATIONS IN PHYSICAL SYSTEMS

DOI: 10.21008/j.0860-6897.2021.2.05
Vibrations in Physical Systems, 32(2):2021205, 2021

Using MLS Methods in Laboratory Measurement of Airborne Sound Insulation

Dominik MLECZKO

Corresponding author: Dominik MLECZKO, email: dmleczko@agh.edu.pl

AGH University of Science and Technology, al. Adama Mickiewicza 30, 30-059 Kraków

Abstract Following the requirements of ISO 10140, to determine the acoustic insulation, measurements of the sound pressure levels in the source (L_1) and receiving (L_2) rooms and the reverberation time measurements in the receiving room (T) should be performed. However, the standard does not indicate the measuring signal to be used for the measurements. Various measurement methods can be used, including the use of the broadband noise or MLS method. The article examines the influence of the applied measurement methodology on the determined spectra of acoustic insulation and the weighted sound reduction index R_w. The total uncertainty of determining the acoustic insulation properties and partial uncertainties in determining L_1, L_2 and T were also calculated. The analysis of the obtained results allows concluding that the applied measurement method has no significant impact on the obtained acoustic insulation values, and the obtained measurement differences may rather be the result of an insufficient sample size.

Keywords: sound insulation, sound transmission loss, MLS method

1. Introduction

In order to determine the acoustic insulation of building materials, measurements of the acoustic pressure levels and the reverberation time should be performed. In laboratory conditions, broadband noise is usually used for this purpose, according to the ISO 10140 [1] standard for laboratory measurement of sound insulation of building elements. The sound generated in the source room shall be steady and have a continuous spectrum in the considered frequency range. If broadband noise is used, white noise is recommended, but it is only a recommendation, and for the measurements, you can use different signals. In addition to broadband noise, where white and pink noise are most commonly used, one can also use the Maximum-Length Sequence (MLS) method [2], which belongs to the impulse methods.

The MLS method has been used for a long time to measure the acoustic properties of interiors in conditions of increased background noise and in places where disturbances may occur. Classic methods of measuring sound insulation are limited to cases where the signal-to-noise ratio is at least 6 dB. In situ measurements, it is recommended that it be even 15 dB, which may be challenging to meet in practice. In such situations, it is necessary to increase the power of sound. This can be done by limiting the broadband noise to an individual frequency band (for example 1/1 octave). However, it may still not be sufficient. This problem can be overcome by using an MLS signal [3].

In laboratory conditions, measurements are made in coupled reverberation rooms built of massive walls and separated from each other and the external environment. It allows obtaining a low level of acoustic background inside them. Thanks to this, getting the appropriate signal-to-noise ratio is not a problem for most tested materials. Signal processing for MLS measurements is more complex than broadband noise measurements, which implies accepting longer measurement times. However, the question arises whether measurements using various methods mentioned above will give comparable results of both the airborne sound insulation spectrum as well as the weighted sound reduction index R_w.

2. Measurements in accordance with the requirements of ISO-10140

The airborne sound insulation from the air sounds is expressed by the formula:

$$R_w = 10\log\frac{P_1}{P_2}, \tag{1}$$

where P_1 is sound power incident on the baffle (proportional to the sound pressure level in the source room, L_1), P_2 is the acoustic power radiated by the baffle (proportional to the sound pressure level in the receiving room, taking into account its acoustic absorption, with the surface of the sample related to 1 m^2.

As a result, formula (1) takes a useful form expressed in formula (2), using the difference in sound pressure levels between the source and receiving rooms assuming that the sound fields in both rooms are perfectly diffused, and the sound energy is transferred only by the tested material.

$$R = L_1 - L_2 + 10\log\left(\frac{S}{A}\right) \text{ [dB]}, \tag{2}$$

where L_1 is the energy average sound pressure level in the source room, L_2 is the energy average sound pressure level in the receiving room, S – is the area of the free test opening in which the tested element is installed, A is equivalent sound absorption area in the receiving room.

It is also necessary to measure sound absorption in the receiving room, which is determined from the Sabine formula:

$$A = \frac{0.161V}{T}, \tag{3}$$

where V is the volume of the receiving room, T is the reverberation time T_{20} in the receiving room.

Laboratory measurements of the sound insulation were carried out in the laboratory equipped with coupled reverberation rooms where the tested material is placed between the rooms. The laboratory is located in the Department of Mechanics and Vibroacoustics of the AGH University of Science and Technology in Kraków (source and receiving). The laboratory consists of two rooms: the source room with a volume of 178.77 m^3 and the receiver room with 176.9 m^3. Between the chambers is a measuring hole with dimensions 1 × 2 m. For the needs of testing small samples, an additional barrier was made, placed in the measuring window, with dimensions 0.7 × 0.7 m (see Fig. 1). This partition is characterized by the weighted sound reduction index R_w equal to 50 dB, which allows omitting lateral transmission when analyzing the results. The laboratory meets most of the guidelines contained in the standard [4], except for the reduced dimensions of the measuring window (the required area is 10 m^2) [5].

Fig. 1. View of the receiving room along with the measuring hole in the laboratory at AGH University of Science and Technology in Cracow.

The measuring path consists of two Norsonic ½" type 1220 pressure microphones, a JBL 2 × 150 VA loudspeaker, the Sound KRAK 200 VA power amplifier and two channel Norsonic RTA 840 analyzer, which at the same time was used as a measuring signal generator: broadband white noise (in the case of reverberation time measurements the Interrupted Noise Method was used) and MLS signal. The meteorological conditions, unchanged during the whole measurements, were: temperature 22°C, relative humidity 56%, and atmospheric pressure 1001 hPa.

3. Measurement uncertainty

If the measurement or prediction result depends on many input parameters, then the uncertainty of this result is the uncertainty function of the partial input parameters [6]. If they are not correlated, the uncertainty of the final result can be calculated using the law of uncertainty propagation[7]:

$$u = \sqrt{\sum_{i=1}^{n} \left(\frac{\partial f}{\partial X_{in(i)}} \right)^2 u_i^2}\,, \tag{4}$$

where u_i – the partial uncertainty of the i-th parameter of the input function f, in the case of acoustic insulation tests, defined by the general dependence (2), $X_{in(i)}$ is the i-th input parameter of the function f defining the acoustic insulation according to the formula (2).

In general, the uncertainty of laboratory measurement of sound insulation will be a function of partial uncertainties specified in the equation [8]:

$$u = f(u_{L1}, u_{L2}, u_T, u_i, u_a, u_f, u_m), \tag{5}$$

where u_{L1} is the partial uncertainty of the sound pressure level measurement in the source room. u_{L2} is the partial uncertainty of the sound pressure level measurement in the receiving room, u_{T2} is the partial uncertainty of the reverberation time measurement in the receiving room, u_i is the uncertainty of the measurement system along with calibration, u_a is the measurement uncertainty (repeatability) of fixing the sample in the test opening, u_f is the measurement uncertainty of lateral transmission, u_m is the measurement uncertainty caused by the variability of meteorological conditions.

Uncertainties associated with measuring the area of the sample and geometrical parameters of the receiving room were omitted, as much smaller than the others [9]. In further calculations, the uncertainty brought by the variability of environmental conditions was not taken into account, as the measurements were made under almost identical conditions (humidity, temperature and pressure) and the sensitivity of the result to the variability of these parameters is small [10]. The uncertainty introduced by fixing the test sample (u_a) and the lateral transfer uncertainty were not taken into account, because the tests were performed for one sample, fixed permanently for all variants of tuning the receiving room. The uncertainty brought by the measuring system along with the calibration was adopted equal to 0.5 dB in all frequency bands.

Uncertainties u_{L1}, u_{L2} and u_{T2} were determined according to the formula:

$$U_i = \frac{s_i}{\sqrt{n}} t_{(n-1;0.975)}, \tag{6}$$

where s_i is the standard deviation of the relevant variable, n is the size of the measurement sample and $t_{(n-1;0.975)}$ is the Student's t-distribution quantile. Propagation coefficients for u_{L1} and u_{L2} were assumed to be equal one, whereas for u_{T2} as the T function expressed in the formula:

$$\frac{\partial R}{\partial T_2} = \frac{10}{\ln 10 \cdot T}. \tag{7}$$

4. Results and discussion

As part of this work, measurements of the acoustic insulation of a sample made of a homogeneous polyethylene (PE) plate with dimensions of 0.7 m x 0.7 m and thickness h=0.01 mm were performed. The comparative assessment was carried out in terms of both the results of measurements of specific sound insulation (together with the weighted sound reduction index R_w according to [11]), as well as the dispersion of the obtained values L_1, L_2 and T, determined on the basis of the standard deviation, which was also used to calculate the measurement uncertainty.

L_1, L_2 i T values were determined from 20-element measurement trials. The measurements were carried out using two different positions of the sound source - 10 measuring positions for each position. The reverberation time studies in the case of broadband noise were performed with the use of the Interrupted Noise Method.

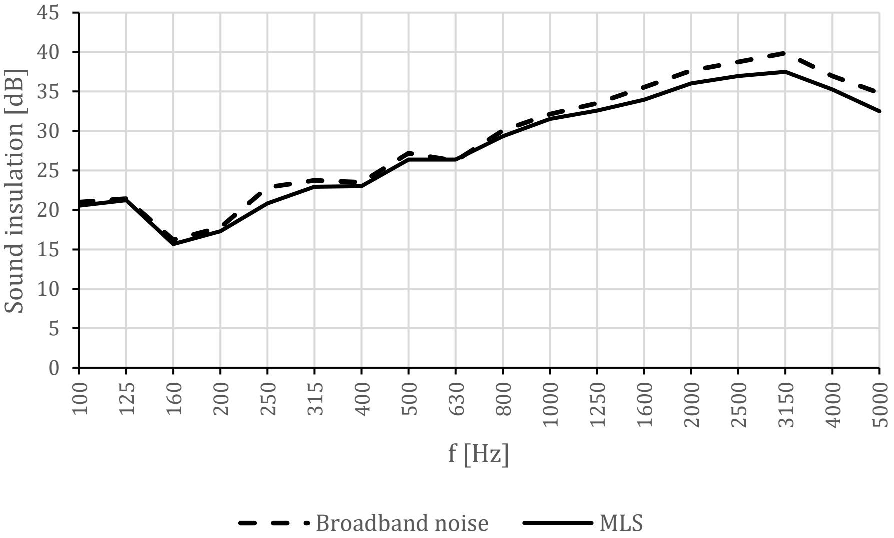

Fig. 2. Acoustic insulation characteristics obtained from laboratory tests of a polyethylene plate with dimensions 0.7 x 0.7 m and thickness h=0.01 m using broadband noise and MLS signal.

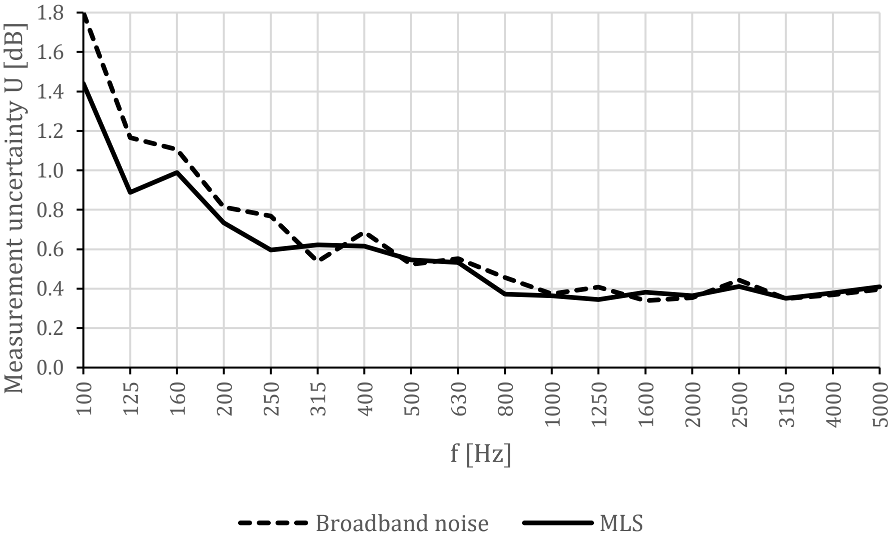

Fig. 3. Characteristics of the measurement uncertainties of the acoustic insulation of a polyethylene plate with dimensions 0.7 x 0.7 m and thickness h=0.01 m using broadband white noise and MLS signal.

Tab. 1. The results of measurements of acoustic insulation in 1/3 octave bands and the weighted sound reduction index R_w

f, Hz	broadband noise		MLS		broadband noise – MLS	
	R, dB	U_c, dB	R, dB	U_c, dB	ΔR, dB	ΔU_c, dB
100	21.0	1.8	20.6	1.4	0.4	0.4
125	21.4	1.2	21.2	0.9	0.2	0.3
160	16.2	1.1	15.7	1.0	0.5	0.1
200	17.8	0.8	17.3	0.7	0.5	0.1
250	22.9	0.8	20.8	0.6	2.0	0.2
315	23.8	0.5	22.9	0.6	0.8	-0.1
400	23.5	0.7	23.0	0.6	0.5	0.1
500	27.2	0.5	26.4	0.5	0.8	0.0
630	26.2	0.6	26.4	0.5	-0.2	0.1
800	30.1	0.5	29.3	0.4	0.7	0.1
1000	32.1	0.4	31.5	0.4	0.6	0.0
1250	33.5	0.4	32.6	0.3	0.9	0.1
1600	35.6	0.3	34.0	0.4	1.6	-0.1
2000	37.6	0.4	36.0	0.4	1.6	0.0
2500	38.7	0.4	37.0	0.4	1.8	0.0
3150	39.9	0.3	37.5	0.4	2.4	-0.1
4000	36.9	0.4	35.2	0.4	1.7	0.0
5000	34.8	0.4	32.5	0.4	2.3	0.0
$\boldsymbol{R_w}$	**31.0**	**0.6**	**30.2**	**0.6**	**0.8**	0.0

The results of laboratory tests as characteristics of acoustic insulation are shown in Fig. 2. Figure 3 shows the characteristics of measurement uncertainties of acoustic insulation, while Table 1 presents the results of measurements of acoustic insulation in 1/3 octave bands and the weighted sound reduction index R_w with expanded uncertainty of measurement u_c, taking into account partial uncertainties specified in relation (5).

The results of the sound insulation measurements presented in Fig. 2 and in Tab. 3 show a great similarity, especially in the low frequency range, with slightly more significant variation in the higher bands. However, it should be noted that, despite the high concordance of the results in the low frequency range, there is also a large uncertainty there. This may indicate to some extent the randomness of the result and the need to carry out tests in a larger number of measurement points.

From the 1000 Hz band, the results of acoustic insulation obtained from the broadband noise method are marginally higher than the results from the MLS method. The most significant difference, amounting to 2.4 dB, occurs in the 3150 Hz band. The situation is the opposite if we consider the measurement uncertainty (see Fig. 3 and Tab. 1). It is more significant in measurements using broadband noise compared to MLS, but only in the low frequency range. In the range of higher frequencies, both the uncertainty itself and its differentiation using various measurement methods decrease. The difference in the R_w value is 0.8 dB, but the difference will already be 1 dB when presented as an integer.

In order to assess which measurement results have the greatest impact on the results of acoustic insulation, the statistical analysis was extended and an additional study was carried out to determine how the choice of the method used affects the results of measurements of L_1, L_2 and T. Uncertainties of input parameters were determined according to the formulas contained in chapter 3. Figures 4, 5 and Table 2 summarize the results of the participation of uncertainty variables L_1, L_2 and T in total uncertainty of acoustic isolation of the sample. Table 2 additionally presents the calculated differences between the uncertainties of the input variables with the use of broadband noise and MLS to facilitate the comparison of the obtained results.

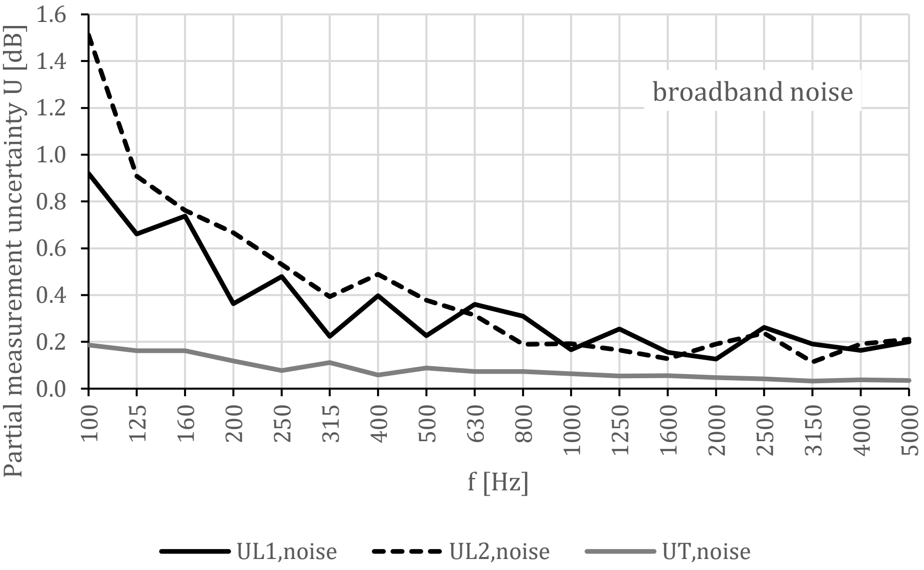

Fig. 4. The share of the measurement uncertainty of variables L_1, L_2 and T in the total uncertainty of the acoustic insulation of a polyethylene sheet with dimensions of 0.7 x 0.7 m and thickness h = 0.01 m using broadband noise.

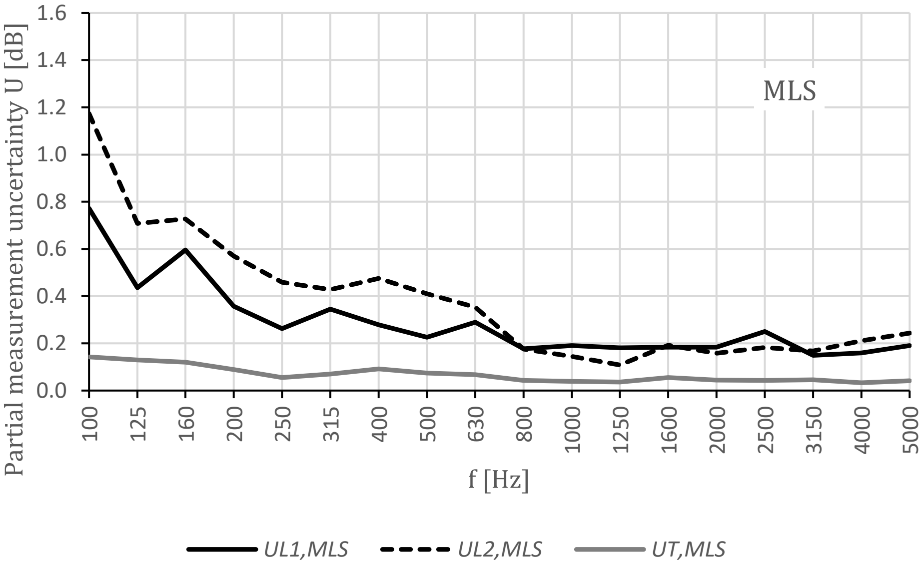

Fig. 5. The share of the measurement uncertainty of variables L_1, L_2 and T in the total uncertainty of the acoustic insulation of a polyethylene sheet with dimensions of 0.7 x 0.7 m and thickness h = 0.01 m using MLS.

Tab. 2. The share of the measurement uncertainty of variables L_1, L_2 and T in the total uncertainty of the acoustic insulation of a polyethylene sheet with dimensions of 0.7 x 0.7 m and thickness h = 0.01 m using broadband noise and MLS.

f, Hz	broadband noise			MLS			broadband noise – MLS		
	$U_{L1,noise}$ dB	$U_{L2,noise}$ dB	$U_{T,noise}$ dB	$U_{L1,MLS}$ dB	$U_{L2,MLS}$ dB	$U_{T,MLS}$ dB	ΔU_{L1} dB	ΔU_{L2} dB	ΔU_T dB
100	0.92	1.51	0.19	0.77	1.17	0.14	0.15	0.34	0.04
125	0.66	0.91	0.16	0.44	0.71	0.13	0.23	0.20	0.03
160	0.74	0.76	0.16	0.60	0.73	0.12	0.14	0.04	0.04
200	0.36	0.67	0.12	0.36	0.57	0.09	0.01	0.10	0.03
250	0.48	0.53	0.08	0.26	0.46	0.05	0.22	0.07	0.02
315	0.22	0.39	0.11	0.35	0.43	0.07	-0.12	-0.03	0.04
400	0.40	0.49	0.06	0.28	0.48	0.09	0.12	0.01	-0.03
500	0.23	0.38	0.09	0.23	0.41	0.07	0.00	-0.03	0.01
630	0.36	0.31	0.07	0.29	0.35	0.07	0.07	-0.04	0.01
800	0.31	0.19	0.07	0.18	0.18	0.04	0.13	0.01	0.03
1000	0.17	0.19	0.06	0.19	0.14	0.04	-0.03	0.05	0.02
1250	0.25	0.17	0.05	0.18	0.11	0.04	0.07	0.06	0.02
1600	0.16	0.13	0.06	0.18	0.19	0.05	-0.03	-0.06	0.00
2000	0.13	0.19	0.05	0.18	0.16	0.04	-0.06	0.03	0.00
2500	0.26	0.24	0.04	0.25	0.18	0.04	0.01	0.05	0.00
3150	0.19	0.11	0.03	0.15	0.17	0.05	0.04	-0.05	-0.01
4000	0.16	0.19	0.04	0.16	0.21	0.03	0.00	-0.02	0.00
5000	0.20	0.21	0.03	0.19	0.24	0.04	0.01	-0.03	-0.01

Based on the results presented in Fig. 3, Fig. 4 and Tab. 2, it can be concluded that the main components of the measurement uncertainty of the acoustic insulation, regardless of the chosen method, are the uncertainties of the input parameters L_1 and L_2. In both cases, the measurement uncertainty significantly decreases with the increase of the central frequency of the measurement band. It can also be noticed that in the vast majority of bands the measurement uncertainty of the results obtained with the broadband noise method is greater than for the MLS method. The contribution of the uncertainty component of the reverberation time to the total uncertainty of the acoustic insulation result is secondary and very similar for both measurement methods.

5. Summary

As part of this work, laboratory tests of airborne sound insulation of a polyethylene plate with dimensions of 0.7 x 0.7 m and thickness h = 0.01 m were carried out. Measurements were carried out on a set of reverberation chambers using two measurement methods. The first was the use of broadband white noise (the Interrupted Noise Method was used in the case of reverberation time measurements), the second was the MLS method. Based on the measurement results, the spectral characteristics of the acoustic insulation and the weighted sound reduction index R_w were determined. It turned out that in the case of both methods, the obtained results are very similar, especially in the range of lower frequencies. Slightly more significant differences can be observed for the range above 1000 Hz. A more substantial difference occurs in the case of the weighted sound reduction index R_w, as it is 0.8 dB, and after conversion to an integer, it will be 1 dB, which in some cases may be necessary. The analysis was extended with an additional study to determine the impact of individual input components on the insulation results. It turned out that the main components of measurement uncertainty are the uncertainties of the parameters L_1 and L_2. The share of the reverberation time component is much less important. Therefore, to increase the accuracy of the measurement results, one should focus on reducing the uncertainty of determining the levels of L_1 and L_2, for example, by increasing the number of elements for each measurement [12]. It may turn out that the results of acoustic insulation obtained in both methods come closer to each other, the difference in the determined R_w will disappear. It should also be mentioned that the tests were performed for only one sample, so the conclusions apply only to that sample. In order to be able to draw general conclusions, more samples should be tested.

Acknowledgments

Funding: This work was supported by the subvention of the Polish Ministry of Science and Higher Education no. 16.16.130.942/kmiw.

Additional information

The authors declare no competing financial interests.

References

1. ISO 10140-4. Acoustics — Laboratory measurement of sound insulation of building elements — Part 4: Measurement procedures and requirements. 2021,
2. C.C. Hak, N.H. Van Hout, H.J. Martin. Measuring Sound Insulation using Deconvolution Techniques. J. Acoust. Soc. Am., 123:3501-3501, 2008.
3. C. Hopkins. Sound Insulation. Routledge 2020.
4. ISO 10140-2. Acoustics. Laboratory measurement of acoustic insulation of building elements. Part 2: Measurement of airborne sound insulation. 2011.
5. K. Kosała, L. Majkut, D. Mleczko, R. Olszewski, T. Wszołek. Accuracy of prediction methods for sound insulation of homogeneous single baffles. Vibrations in Physical Systems, 31(2):20202010, 2020.
6. D. Mleczko, T. Wszołek. Variability influence of input parameters on result of room acoustic calculation. Acta Phys. Pol. A, 118:128-130, 2010.
7. ISO/IEC Guide 98-3:2008 (JCGM/WG1/100). Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement. 2008.
8. T. Wszołek. Uncertainty of sound insulation measurement in laboratory. Arch. Acoust., 32(4S):271-277, 2007.
9. W. Batko, P. Pawlik. New Method of Uncertainty Evaluation of the Sound Insulation of Partitions. Acta Phys. Pol. A, 123(6):1012-1015, 2013.
10. D. Mleczko, T. Wszołek. Effect of diffusing elements in a reverberation room on the results of airborne sound insulation laboratory measurements. Arch. Acoust., 44(4):739–746, 2019.
11. ISO 717-1:2021-06. Acoustics – Rating of sound insulation in buildings and of building elements – Part 1: Airborne sound insulation. 2021.
12. P. Pawlik, B. Przysucha. Wpływ liczby punktów pomiarowych na niepewność wyznaczania izolacyjności akustycznej przegród budowlanych [In English: The effect of number of measurement points on the uncertainty of the determination of sound insulation of building partitions]. Pomiary Autom. Kontrola, 60(12):1124–1126,2014.