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Uncertainty of airborne sound insulation index measurement in laboratory conditions

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Protection against noise is one of essential requirements of the European Union directive. In buildings airborne sound insulation is used to define the acoustic quality of walls between rooms. However the evaluation of sound reduction index is sometimes difficult or even ambiguous, both in real world and laboratory measurements, in spite of the fact that there are some unified measurement procedures specified in the ISO 140 standards. There are problems with the reproducibility and repeatability of the measurement results. Some difficulties may be caused by non-diffuse acoustic fields, non uniform reverberation time or errors of the reverberation time measurements. Some minor obstacles are also posed by flanking transmission – quality of the sample fixing in the measuring window and the S/N ratio. The paper deals with an analysis of partial uncertainties of the above mentioned measurement components and their influence on the combined uncertainty in 1/3 octave frequency bands and the sound reduction index determined according to ISO 140-3, using the uncertainty propagation law.

1 Introduction

In buildings the airborne acoustic insulation is used for assessment of the acoustic quality of walls between rooms. However the evaluation of acoustic insulation happens to be difficult, even sometimes ambiguous, not only in the field conditions, but also in the lab, in spite of the fact that there are unified measurement procedures specified in the ISO 140 and ISO 717 standards. Whereas in the field conditions some problems might be encountered with fulfilling all the standard requirements, particularly in assessment of flanking transmission, there should be no such problems, or to a very limited extent, in the laboratory conditions. Still it is not so. There are problems mainly with reproducibility of the results, what can be confirmed by e.g. the inter-laboratory study results described in papers [1]. The problems with reproducibility are even encountered for different studies of the same laboratory. The origins might lie in the inhomogeneities of the acoustic field in the measuring (source and receiving) rooms, space variation of the reverberation time in the receiving room, and additionally errors of the reverberation time measurements, particularly in the low frequency band [1]. Further factors are the flanking transmission and acoustic background, in particular for high values of the sound reduction index R. A separate problem is the method of sample fixing in the measurement window. A proper sample sealing, particularly when its edges are not very smooth (as it is for the glass window panes), may be cumbersome, and its effect on the measurement result quite considerable. In the studies of sound reduction index carried out in the Dept. of Mechanics and Vibroacoustics in the AGH-UST [4] it has been shown that the measurement error of Rw, related to improper sample sealing may be as high as 3-4 dB, and in individual frequency bands above 1 kHz it may even reach more than 10 dB. However an experienced measurement team can relatively easy notice such an irregularity in R v. frequency. Therefore in the uncertainty analysis such a case has been excluded, and much weaker version has been accepted as actually possible.

In the present work partial uncertainty analysis has been carried out for all the above mentioned factors and their influence has been evaluated on the combined uncertainty in 1/3 octave bands and the Rw index, using the uncertainty propagation law. Some of the partial uncertainties belong to the type B uncertainties, while remaining ones belong to type A. All of the analysis and calculations concern the acoustic insulating power measurement set-up in the complex of reverberation rooms located in AGH-UST Department of Mechanics and Vibroacoustics in Krakow

2 Measuring conditions

The studies of acoustic insulating power are carried out in the complex of reverberation rooms located in AGH-UST in Krakow, which is approximately compatible with the requirements imposed on such laboratories in the ISO 140 series of standards. The deviations mainly concern the reverberation time value in the reception chamber and also an atypical size of the measurement window (2000x1000 mm), located between two conjugated reverberation rooms, with working volumes ca. 180 m^3 each. More detailed description of the laboratory can be found in the paper [6].

A view of a sample assembled in the measuring window has been shown in Fig.1.

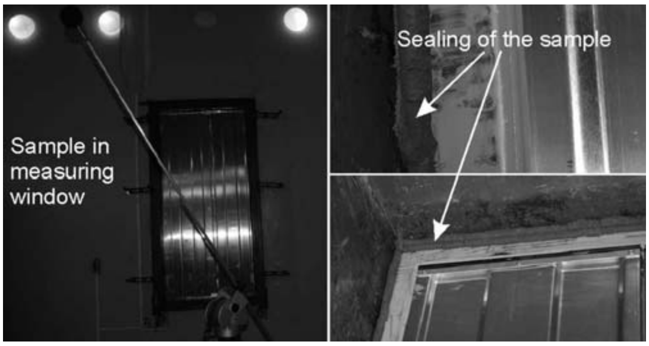
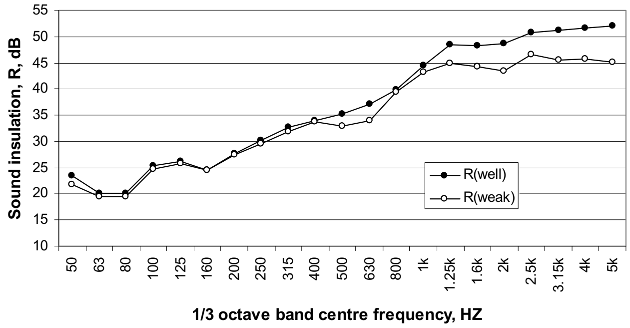


Fig.1.View of a sample assembled in the measuring window.



$Rw(C;Ctr)_{(weak)}$=	39(-1,-5)	C50-3150=	-1 dB	C100-5000=	-1 dB	C50-5000=	-1 dB
		Ctr,50-3150=	-6 dB	Ctr,100-5000=	-5 dB	Ctr,50-5000=	-6 dB
$Rw(C;Ctr)_{(well)}$=	41(-1,-5)	C50-3150=	-1 dB	C100-5000=	0 dB	C50-5000=	-1 dB
		Ctr,50-3150=	-7 dB	Ctr,100-5000=	-5 dB	Ctr,50-5000=	-7 dB

Fig. 2. Plots of sound insulation index in 1/3 octave bands and the Rw sound reduction index, measured with properly and weakly sealed sample. In table below results of C and Ctr corrections.

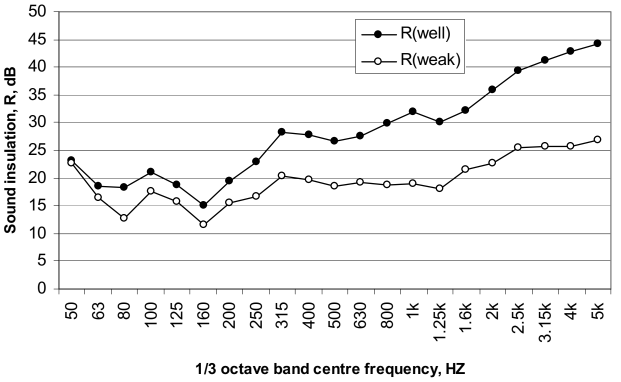


Fig. 3. Plots of sound insulation index in 1/3 octave bands and the Rw sound reduction index, measured with properly and weakly sealed sample.

Various samples are studied in the laboratory - they mostly include integrated window panels, elements of the roadside noise barriers (absorbing or transparent) and the elements of sound-proof casings. With such a sample variety there is actually no universal way for fixing (sealing) the samples in the measurement window. Special requirements imposed on the case of glass panel fixing cannot be directly applied for barriers absorbing sound from the incident side. In practice every barrier is installed automatically, but it is sealed accordingly to each individual case (manually). Such an approach, exhibiting usually best performance, may be the source of some local "leaks", manifested by a decrease of the sound reduction index, R in the 1 to 2.5 kHz band. Example of such a plot of R as a function of frequency for properly and poorly sealed sample has been shown in Fig.2. But one can find some other cases when decreasing of R is visible in whole band of frequency, as in Fig.3.

Measurements of acoustic pressure are performed simultaneously in the emission and reception room, while the reverberation time is measured right after completing the measurement session. All the measurements are performed in 1/3 octave frequency bands in the frequency range from 50 Hz to 5 kHz, in 12 measuring points.

Sound reduction index, R of the sample is determined according to the formula:

$$R = L_{p,S} - L_{p,R} + 10\log\frac{S}{A} \qquad (1)$$

where $L_{p,S}$ is the average sound pressure level in the diffuse sound field of the source room, $L_{p,R}$ is the average sound pressure level in the diffuse field of the receiving room, S is the area of the test sample, A is the absorption area of the receiving room, in this work determined from the reverberation time T30

Typical plots of averaged acoustic pressure levels in the source and receiving rooms (with the respective standard deviations) and the acoustic background in the receiving room have been shown in Fig.4, while the reverberation time T30 values for the receiving room, also with their standard deviations, have been shown in Fig.5.

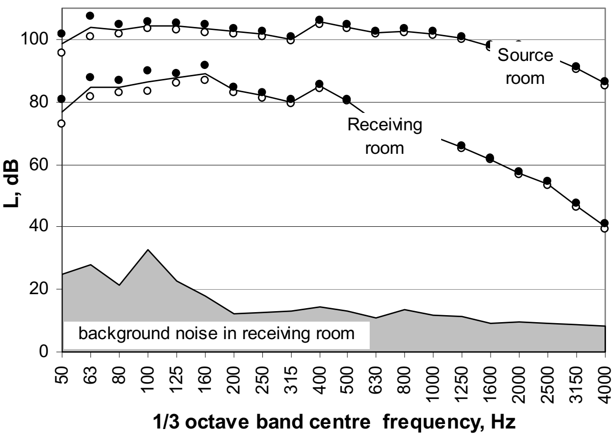


Fig.4.Averaged levels of acoustic pressure in the source and reception room and background noise in the reception room

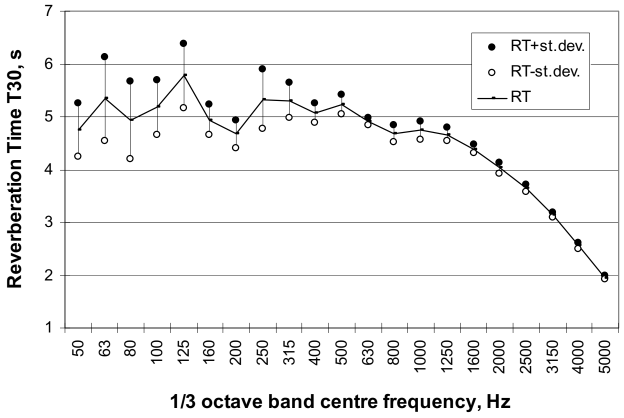


Fig.5.Averaged values of reverberation time T30 in the reception room together with the standard deviations

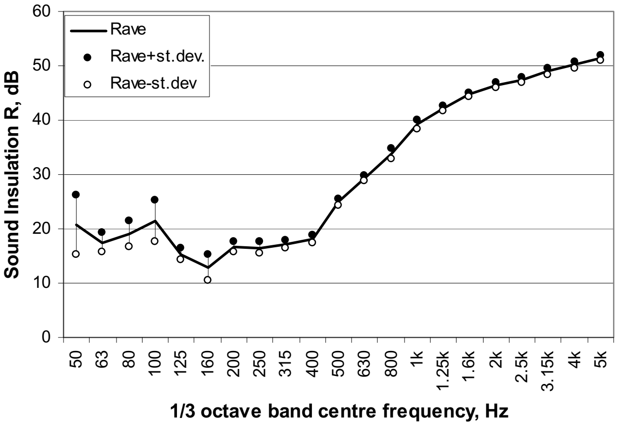


Fig.6. Plots of sound reduction index in 1/3 octave bands and the Rw sound reduction index with standard deviations.

As can be seen from the above figures, both the acoustic pressure levels plots as well as the reverberation time plots are characterized by greater spreads in the low frequency range, therefore in that area the greatest contributions to the measurement uncertainty should be expected

3 Analysis of measurement uncertainty

If the measured or predicted noise level depends on many input values then the final result is a function of many arguments [13]:

$$L_{out} = f(X_{in1} + X_{in2} + ... + X_{inm}) \qquad (2)$$

everyone of which carries some standard uncertainty U(Xini). Combined standard uncertainty Uc(Lin), under assumption that the individual arguments in formula (2) are independent, can be calculated using the formula (3):

$$u_c(L_{out}) = \sqrt{\sum_{i=1}^{m} \left(\frac{\partial f}{\partial X_{ini}} \right)^2 u^2(X_{ini})} \qquad (3)$$

The uncertainty provided together with the measurement result is a multiplicity of the combined standard uncertainty and is usually called an extended uncertainty

Formulas (1) and (3) have been used for analysis of sensitivity of the combined uncertainty with respect to its individual components. The partial uncertainties of the measurements of acoustic pressure levels and reverberation times belong to the type A standard uncertainties, while all the other ones belong to the type B. Plot of uncertainties of the sound pressure level in the source (UAL1) and the reception (UAL2) room and reverberation time (UART) in the reception room has been shown in Fig. 7. It is worth to notice relatively low uncertainty of reverberation time measurement in compare to the uncertainty of sound pressure level measurements.

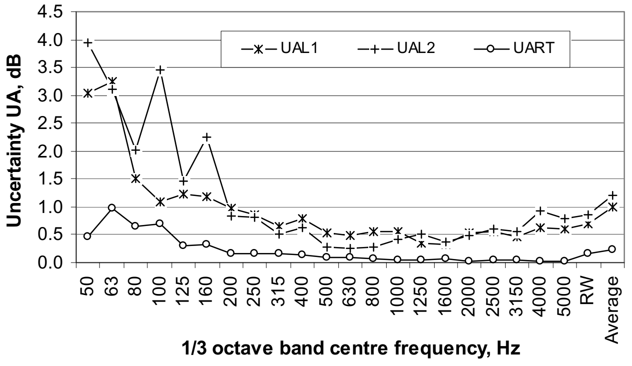


Fig.7. Standard uncertainty type A of sound level and reverberation time measurement

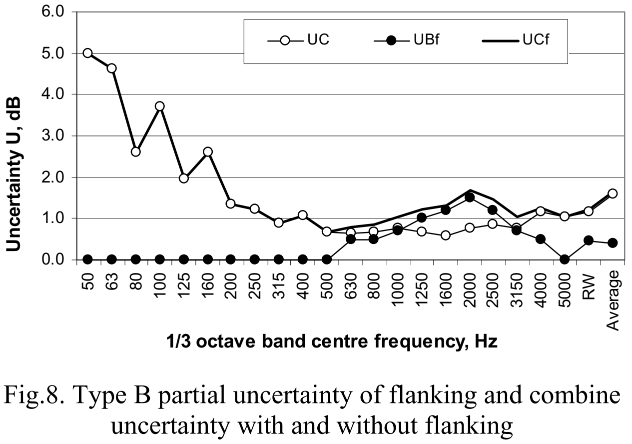


Fig.8. Type B partial uncertainty of flanking and combine uncertainty with and without flanking

In evaluation of the type B uncertainty for each variable the possible variability range during the measurement duration has been assumed, with additional a priori assumption of homogenous distributions of the respective variables. In such a case the standard uncertainty is given as of the respective variability range (spread). A similar rule can be accepted when taking the acoustic background into account, however in the example presented above (see Fig.4) the distance from the background is higher than 30 dB in each frequency band, what in consequence reduces the uncertainty to values below 0.01 dB level. Therefore in the uncertainty budget for the example from Fig.4 the respective contributions have been neglected. An exemplary uncertainty distribution has been shown in Figures 7 and 8. In Fig.8 the combined uncertainty Uc has been shown, without taking the flanking sound transmission into account and uncertainty Ucf with such flanking "leaks" taken into account. As can be seen in the presented example the effect of such a leak on the total uncertainty of the Rw index is rather moderate (0.09 dB), with the index uncertainty value of 0.46 dB, however in some cases (as has been mentioned in the Introduction) it can even reach a value of several dB.

The effect that is not shown in Fig.8 is the additional uncertainty resulting from fitting of the actual insulation index R curve to the normalized curve (acc. to EN ISO 717-1). This uncertainty was equal to 0.29 dB, and its effect on the total uncertainty of the Rw index was about 0.06 dB

4 Conclusion

The completed uncertainty analysis for laboratory measurement of acoustic insulating power of barriers has shown that the greatest effect on the final value comes from the inhomogeneity of acoustic fields, both in the source (0.7 dB) and reception (0.86 dB) rooms and from the quality of sample sealing in the measurement window (0.46 dB).

The total measurement uncertainty of the sound reduction index Rw for the case discussed above is equal to 1.15 dB, and with taking into account a possible sound leak the respective uncertainty increases to 1.24 dB. As expected the measurement uncertainty considerably increases in the low frequency range, what is in consequence the source of uncertainty increase for the Rw(C,Ctr) indices if the frequency band is extended down to the frequency of 50 Hz. (usually the Rw index is determined in the 100 - 3150 Hz range). The respective uncertainties of Rw(C,Ctr) determination in the 50 - 3150 Hz frequency band are given as:

homogeneity of acoustic fields - 1 dB in the source room, 1.2 dB in the reception room, what gives the total uncertainty of 1.6 dB. The uncertainty related to the sample sealing is slightly reduced to 0.38 dB.

References

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