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A. Jagniatinskis & B. Fiks

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INVESTIGATION OF THE ACCURACY IN LABORATORY SOUND INSULATION MEASUREMENTS

A. Jagniatinskis, B. Fiks
Institute of Thermal Insulation

1. Introduction

Airborne noise insulation is an important parameter for set aspiration level for acoustics quality of construction materials and buildings elements. Sound insulation of building elements is frequency dependent and is represented by sound reduction index R which is normally determined from series sound level difference measurements in connected reverberation rooms and calculations from the equation [1–3]:

$$R = L_1 - L_2 + 10lg\frac{ST}{0{,}16V}, \qquad (1)$$

where L_1, L_2 are measured mean sound pressure levels in source room and receiving room respectively, dB; S is area of the test specimen, m^2; V is volume of the receiving room, m^3; T is reverberation time in the receiving room, s.

Determination of the sound insulation for partitions, windows and doors is specified in various foreign standards [4–7]. These standards impose strong restrictions on the shape and volume of reverberation room, acoustical field diffusibility in the room and on the accuracy of R value determination. Always there are difficulties in obtaining good accuracy of results. As far as the measurements carried out in the diffused sound field are concerned, statistical methods are used to estimate the test accuracy. General requirements of main foreign standards relating to the accuracy and conditions of measurements are listed in Table 1. It can be concluded from this table that there are some differences in these data and for factitious with higher requirements for test room volumes we have less strong requirements for precision.

2. Description of test facility

We use facilities with following parameters for measurements: the volume of source and receiving rooms are 70 m^3 and 100 m^3 respectively; 1/3 octave frequency band of interest is 100-3150 Hz. For tests measurements are used 6 or 12 microphone positions in every room, up to 22 series of reverberation time measurements (6 registrations in every series) in receiving room. From Table 1 we can see that volumes of rooms for frequencies below 160 Hz are significantly smaller than it is required in Australian and USA standards and are in accordance with European and Russian standards.

Let's show, using statistical estimations of experimental data, that measurements under European standard requirements in these test rooms are valid and sufficiently precise. Also, we will obtain the necessary number of microphone positions for determination sound pressure levels L_1 and L_2 and number of reverberation time T measurements, which bring desirable precision in one-third octave frequency band.

3. Statistical estimations

If values L_1, L_2, and T in equation (1) are random and independent, an estimation of error ΔR of value R in equation (1) may be expressed as follows:

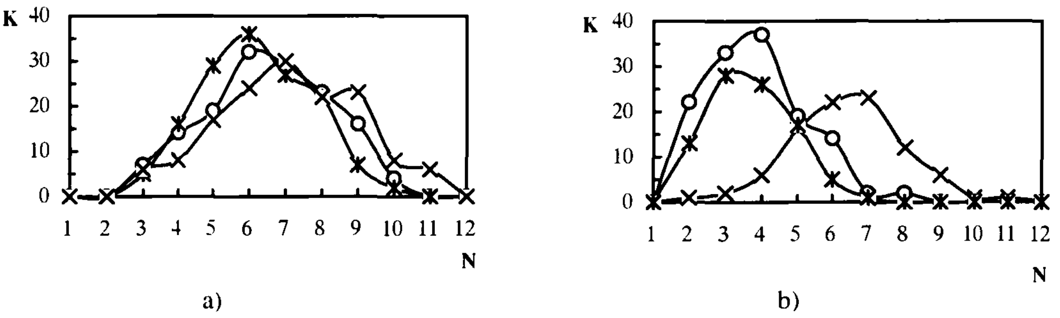
$$\Delta R^2 = \Delta L^2 + \frac{18{,}49}{T^2}\Delta T^2, \qquad (2)$$

where ΔL is error of value $L = L_1 - L_2$; ΔT is error of reverberation time T measurements.

The validity of next statistical estimations was provided by series of tests. Experiment conditions did not differ from those of a usual laboratory test. The number of microphone positions in every test room was 12 (so we get 144 values of difference L), and number of reverberation time, T measurements in low frequency bands was up to 130. Estimations of probability distributions of L and T random values obtained from experimental data for some frequency bands are shown in Fig 1.

Overview of different standards for sound reduction index determination

	USA (E90-90)	Australia (AS1191-85)	Russia (GOST 27296-87)	European Union (LST EN ISO140-3:1999)
Frequency range of interest in 1/3 octave band, Hz	125-4000	100-5000	100-3150	100-5000
Test room volume, m^3	80 and 125 (< 125 Hz)	100 and 163 (100 Hz)	50	50
	Standard deviation		Repeatability	
Accuracy in frequency band, dB	3: 125,160 Hz 2: 200,250 Hz 1: 315-4000 Hz	3,7: 100 Hz 3,5: 125 Hz 3,3: 160 Hz 3,0: 200 Hz 2,5: 250 Hz 2,0: 315 Hz 1,6: 400 Hz 1,3: 500 Hz 1,1: 630-5000 Hz	5: 100, 200 Hz 3: 250 Hz 2: 315-500 Hz 1: 630-1250 Hz 2: 1600-3150 Hz	4,5: 100 Hz 4,0: 125 Hz 3,5: 160, 200 Hz 2,5: 250, 315 Hz 2,0: 400, 500 Hz 1,5: 630-3150 Hz
Recommended number of microphone positions	–	3	6	5



a) b)

Fig 1. Experimental distribution densities: a) for values *L* in frequency bands: o – 100 Hz; * – 800 Hz; x – 3150 Hz and b) for values *T* in frequency bands: o – 100 Hz; x – 400 Hz; * – 800 Hz, where *N* is number of intervals and *K* is quantity of hitting for random values *L* or *T* in the corresponding interval

We can see from Fig 1 that the distribution of random values *L* and *T* correspond to a normal distribution shape, what was expected for diffuse acoustical field conditions. Quantitatively it may be tested by the Hi-square criterion for statistical hypothesis verification [8]. Achieved significance levels are illustrated in Fig 2 obtained by comparing distributions of measurement data with normal distribution. Conclusion from Fig 2 follows that significance levels of random values of *L* and *T* distributions densities are large enough, and it shows their proximity to the normal distribution density in one-third octave frequency bands.

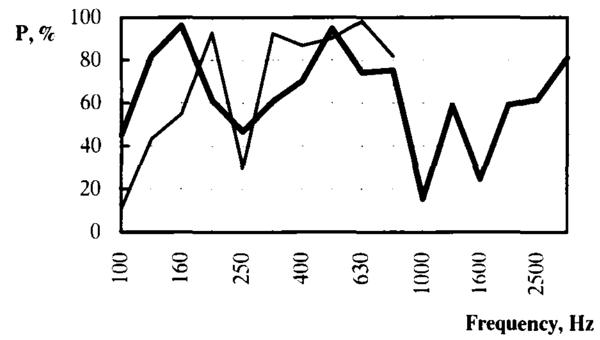


Fig 2. Significance levels *P* obtained by comparing the experimental distributions with normal distribution in 1/3 octave bands for values *L* (—) and *T* (—) respectively

4. The preciseness of sound reduction index determination

For estimating errors ΔL and ΔT from experimental data we use confidence intervals, based on Student's distribution [8]:

$$P\left\{\left|\Delta X\right| < s_x t\left(\gamma, n_x - 1\right)/\, n_x^{1\quad 2}\right\} = \gamma, \qquad (3)$$

where ΔX is mean deviation of measurement value X from true value; s_x is estimated standard deviation of X value; n_x is number of X value determinations (measurements); $t\left(\gamma, n_x - 1\right)$ is Student's t-distribution value with $n_x - 1$ freedom levels and significance level γ; $X \in \{L, T, R\}$.

Formulae (2), taking into account (3), are expressed as follows:

$$\left|\Delta R\right| < \left[s_L^2 / n_L t^2\left(\gamma, n_x - 1\right) + \frac{18{,}49}{\overline{T}^2} \times \right. \qquad (4)$$
$$\left. \times s_T^2 / n_T t^2\left(\gamma, n_T - 1\right) \right]^{\quad 2},$$

where $\overline{T}$ is mean value of reverberation time, defined in one-third octave frequency bands.

In accordance with valid standards, it is assumed that γ = 95%. From equation (4) we can calculate the repeatability curves in 1/3 octave frequency bands for various number of L and T measurements. In Fig 3 these calculated curves are shown in comparison with the repeatability of the table. Note that the repeatability values r for USA and Australian standards are recalculated from expression $r = \sqrt{2\Delta R}$ (because the repeatability is determined as difference of two following measurements of value R).

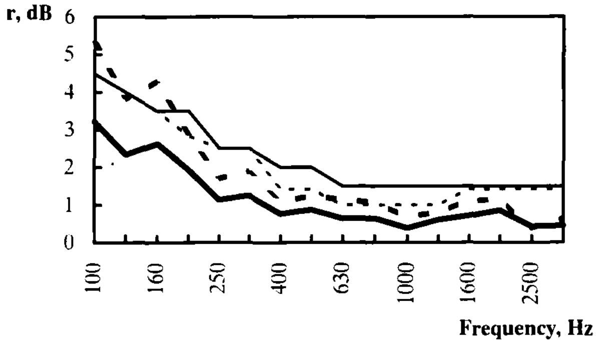


Fig 3. Repeatability values of sound reduction index R obtained from experimental data: for n_L = 12 curve denoted by ' —' line; for n_L = 6 - by '- - -' and taken from standards, listed in Table 1: European – denoted by '---' line; common, with minimum repeatability – by '—' line

The obtained results are shown in Fig 3. To achieve the desirable accuracy in accordance with standard requirements [4–7] it is sufficient to carry out measurements of sound pressure levels in 6 microphone positions in every test room for 1/3 octave bands above 200 Hz and - in 12 positions for 100 Hz, 125 Hz and 160 Hz 1/3 octave bands. It is sufficient to determine reverberation time from one series of measurements with 6 registrations (6 measurements).

Note that the mean value of R in accidence with here mentioned standards is determined on the base of energy mean of measured sound pressure levels [4–7], but all statistical estimations in these standards are based on arithmetic mean value. For this reason all statistical estimations and the confidence interval (4) are not symmetrical. This bias Δ may be estimated. Examine the difference between arithmetic and energy means, which is expressed as follows:

$$\Delta = 1/n \cdot \sum L_i - 10 \cdot lg\left(1/n \cdot \sum \cdot 10^{L_i \quad 10} \right), \qquad (5)$$

where n is number of measurements; $i = 1, \ldots, n$.

Using not difficult transformations and the expansion of function 10^x in Taylor's series we can obtain the sufficiently precise estimation of Δ:

$$\Delta = -10 \cdot lg\left[1 + \left(n - 1\right)/\, n \cdot 0{,}027 \cdot \sigma^2 \right] \qquad (6)$$

where σ^2 is dispersion of measured value L. Estimation (6) may be very important in practice for correction of the confidence interval of measured values. Usually the magnitude of this correction for low frequency octave bands is 0,8–1,0 dB and for high frequency octave bands is about 0,1 dB.

5. Conclusions

Experimental investigations show a sufficient precision in sound reduction index measurements of construction materials and buildings elements in our reverberation rooms. It is proved statistically that the acoustical field produced in these rooms is diffuse. Also, the method of quantitative estimation of diffusibility is proposed. The given expressions allow to estimate more carefully the accuracy of sound reduction index determination from the measured data.

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LABORATORINIŲ GARSO IZOLIAVIMO MATAVIMŲ TIKSLUMO TYRIMAI

A. Jagniatinskis, B. Fiks

Santrauka

Vienas iš svarbesnių statybinių medžiagų ir statinių elementų parametrų yra oro garso izoliavimas. Statybinių elementų garso izoliavimo koeficiento matavimą reglamentuoja įvairių šalių standartai. Juose nurodyti griežti reikalavimai bandymo kameros tinkamumui bei matavimų tikslumui nustatyti. Įvairiuose standartuose šie reikalavimai yra skirtingi (žr. 1 lentelę).

Šio straipsnio tikslas yra parodyti, kaip nustatyti bandymo kameros tinkamumą, bei apibrėžti garso slėgio lygių ir aidėjimo trukmės matavimų kiekį, kad būtų pasiektas reikalaujamas matavimų tikslumas visose trečdalio oktavos dažnių juostose.

Garso izoliavimo koeficientas R yra nustatomas pagal (1) formulę, išmatavus garso slėgio lygius siunčiamojo ir priimamojo garso kamerose L_1 ir L_2 ir aidėjimo trukmę T priimamojo garso kameroje. Bandant buvo naudojamos 100 m^3 (siunčiamojo garso) ir 70 m^3 (priimamojo garso) aidėjimo kameros, atitinkančios Europos standartų reikalavimus. Matuojant bandymo kamerose buvo sukuriamas difuzinis garso laukas. Nuo jo difuziškumo lygio priklauso matavimų tikslumas. Bandymų rezultatai įvertinami remiantis statistine analize.

Darant prielaidą, kad atsitiktinių dydžių L_1, L_2, T tikimybiniai pasiskirstymai atitinka normalųjį (difuziškumo sąlyga) ir yra nepriklausomi, gauta garso izoliavimo koeficiento nustatymo paklaidų įvertinimo formulė (2). Tam, kad būtų patvirtintos daromos prielaidos bei nustatyti kiti matavimo parametrai, buvo atliekami tiriamieji matavimai, panaudojant iki 12 mikrofonų vietų ir iki 22 serijų (130 registracijų) aidėjimo trukmės matavimų. Nustatyta, kad atsitiktinių dydžių $L = L_1 - L_2$ ir T pasiskirstymo tankiai arti normaliajam (1 pav.). 2 pav. pateikti reikšmingumo lygmenys, kai tikrinama hipotezė dėl atsitiktinių dydžių L ir T pasiskirstymo tankių atitikties normaliajam pasiskirstymo tankiui (pagal Hi-kvadrato kriterijų) visose trečdalio oktavos dažnių juostose. Daroma išvada, kad, norint atsitiktiniam dydžiui R nustatyti pasikliautinųjų intervalų ribas, galima taikyti Stjudento pasiskirstymą (žr. (3) ir (4) formules).

Pagal nustatytus su pasikliovimo lygmeniu g=95% garso izoliavimo koeficiento paklaidos DR verčių įvertinimus gautos bandymų matavimų kartojimosi vertės visose trečdalio oktavos dažnių juostose (3 pav.). Iš 3 pav. matyti, kad, norint gauti pageidaujamą tikslumą, remiantis standartų reikalavimais [4–7], pakanka išmatuoti garso slėgio lygius L_1 ir L_2 6-iose mikrofono vietose, kai dažnių juostos viršija 200 Hz, ir 12-oje mikrofono vietų, kai dažnių juostos esti mažiau kaip 160 Hz, o aidėjimo trukmę pakanka nustatyti pagal vieną matavimo seriją su 6-iomis registracijomis.

Pastebėta, kad garso izoliavimo koeficientas nustatomas taikant garso slėgio vidurkio įvertinimus pagal energinį vidurkį, o jo tikslumui įvertinti imamas aritmetinis vidurkis. Dėl tos priežasties pasikliautinųjų intervalų ribų vertės pasislinks tam tikra verte. Gautas gana tikslus pasislinkimo vertės įvertinimas (6) tarp matematinio ir energinio vidurkio. Tai yra svarbu, norint nustatyti garso izoliavimo koeficiento verčių patikslinimą.

Aleksandras JAGNIATINSKIS. Doctor. Head of Acoustic Laboratory. Institute of Thermal Insulation. Linkmenų g. 28, LT-2600 Vilnius, Lithuania. E-mail: aljagn@pub.osf.lt.

Doctor (technical sciences, 1985). Author of more than 50 reports and papers. Research interests: acoustical measurements, building acoustics and protection against noise.

Boris FIKS. Doctor. Senior Research Fellow. Institute of Thermal Insulation, Acoustic Laboratory, Linkmenų g. 28, LT-2600 Vilnius, Lithuania.

Doctor (technical sciences, 1985). Author of more than 30 reports and papers. Research interests: signal and data processing in acoustics and electroacoustics, acoustical measurements.