Noise Reduction Due to Additional Absorption Placement in Rooms

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Abstract. The series of measurements of noise abatement due to placement of known amount of additional absorption has been carried out in the reverberation chamber in NIISF RAASN laboratory. Experimental findings are congruent with the result of calculation using the method developed by the authors with high accuracy. The conducted study make it clear that the method has high accuracy and it can be used during the process of acoustic design of different types of rooms for noise control and noise rating.

Introduction

It is well known that one way of noise control in rooms is reverberation time decrease due to placement of additional materials and constructions, i.e. increasing of absorption in room.

In paper [1] present authors suggest a method of sound pressure level (SPL) abatement calculation in view of known absorption A increase, depending on acoustic properties of the room and distance to sound sources. Suggested method allows for estimating of noise level at different stages of acoustic design.

In noisy places it gives an opportunity to estimate the amount of additional absorption in room (based on in-situ acoustic measurements results), which is needed to keep the noise level down to desired values (e.g. standart noise level).

This article shows a comparison of results received from calculation according to the method [1] and the one based on laboratory measurements of noise reduction due to decreasing the amount of absorption. The article is the follow-up of [1].

1. Theoretical basis of suggested method

The theoretical underpinning of the method was fully reviewed in [1]. To keep the coherence treatment, basic points will be represented below.

It has been known (e.g. [3-7]) that sound energy density \( E \) in each point of the room with a sound source in it could be presented as a sum of direct \( E_d \) and reflected energy \( E_r \) (so-called direct and reflected reverberative components):

\[
E = E_d + E_r
\]  

(1)

Here direct and reflected reverberative components define as:
\[ E_d = \frac{W \Omega}{4\pi r^2 c_0} \]  
\[ E_r = E_{st} (1 - \bar{\alpha}) = \frac{4W}{Bc_0} \]  

Herewith \( E_{st} \) is steady-state sound energy,

\[ B = \frac{A}{\bar{\alpha}} \]  
Where \( B \) is the room constant, m\(^2\);
\( A \) – total absorption of the room, m\(^2\);
\( \bar{\alpha} \) – avg sound absorption coefficient in room;
\( W \) – acoustical power of the sound source, W;
\( \Omega \) – directivity factor;
\( c_0 \) – sound velocity in air, m/s;
\( r \) – distance to sound source, m.

Sound energy density is related to SPL as:

\[ E = p_0^2 \cdot 10^{0.1L} \]  
where \( L \) is sound pressure level (SPL), dB;
\( \rho \) – apparent air density, kg/m\(^3\);
\( p_0 = 2 \cdot 10^{-5} \) – threshold of audibility in sound pressure, Pa.

2. Experiment description and measurement results

A series of SPL reduction \( \Delta L \) measurements due to carrying in known amount of additional absorption was realized in the large reverberation room of Research Institute of building physics, Moscow.

The room has a volume of \( V = 188 \) m\(^3\) and total surface area \( S = 203 \) m\(^2\). A total of 15 points was selected for measurements. Points \( R01-R05 \) were taken at following distances from the source, respectively: 1 m, 1.5 m, 2 m, 3 m, 4 m. Measurement points were distributed along three directions from sound source: \( S01, S02, S03 \). The scheme of measurement points is shown at Figure 1.

Measurements were carried out in two modes:

- Mode 1. Empty reverberation room
- Mode 2. Reverberation room with added absorption material

In each point reverberation time \( T_{30} \) was measured (minimum 3 measurements for each points) according to procedure [9].

SPL measurements were carried out in each point using white noise signal on a source, after which results were averaged over each direction (\( S01-S03 \)) to reduce the influence of sound field irregularity in low frequency range. Signal levels during reverberation time and SPL measurements had the equal power.

As a sound source an omnidirectional loudspeaker was used (dodecahedron type). Reverberation time measurements were carried out with use of EASERA software. SPL was measured by Bruehl&Kjaer type 2250 sound meter and B&K type 4189 measuring microphone unit.

As a sound absorbing material metal perforated panels filled with mineral wool were used. Sound absorption coefficient for these panels had been measured earlier according to standards [10,11], its frequency response is shown on Figure 3.

Measured \( T_{30} \) in two modes, averaged over all points with showed min/max values are presented at Figure 4.

Measured SPL values \( L_R \) for each point \( R \) are presented at Figure 5. Measured noise reduction \( \Delta L_R \) for each point \( R \) is shown at Figure 6.
Measured SPL values $L$ (averaged over all points) in two modes and SPL reduction $\Delta L$ (averaged over all points) are shown at Figure 7 and Figure 8 respectively.

Figure 1. Scheme of measurement points.

Figure 2. Reverberation room view during the experiment.

Figure 3. Sound absorption coefficient of perforated panels

Figure 4. Average measured $T_{30}$ with min/max curves in mode 1 (empty room) and mode 2 (room with added absorption material)

Figure 5. Measured SPL values $L_R$ for each point $R$ in two modes of measurement

Figure 6. Measured SPL reduction $\Delta L_R$ for each point $R$
3. SPL reduction calculation

Variant 1. Statistical approach of sound field

The ratio of $E_d$ and $E_r$ in some point of the room depends on the distance to sound source and its directivity. In measurements an omnidirect source was used, so in further calculations let $\Omega = 1$.

The percentage of $E_d$ from total energy $E$ can be estimated from the proportion:

$$\frac{E_d}{E} = \frac{B}{B + 16\pi r^2}$$  \hspace{1cm} (6)

Calculation results for both modes are shown at Figures 9 and 10. One can see that reverberation radius $R$ in the room is quite short and the ratio of $E_d$ is not too large across a broad spectrum. In this case it is fair to assume that sound field in the room is close to diffuse without significant error. Therefore we can set $\Omega = E_r$ i.e. to consider sound filed in a statistical approach.

Consequently, using (3) and (5), we obtain simple expression:

$$\frac{E_1}{E_2} = 10^{0.1(L_1 - L_2)} = \frac{B_2}{B_1}$$  \hspace{1cm} (7)

$$\Delta L = 10 \log \left( \frac{B_2}{B_1} \right)$$  \hspace{1cm} (8)

Variant 2. Calculation in view of source distance

| Frequency f, Hz | $SPL L$, dB |
|----------------|-------------|
| $10^2$ | 66 |
| $10^3$ | 68 |
| $10^4$ | 70 |

| Frequency f, Hz | $SPL L$, dB |
|----------------|-------------|
| $10^2$ | 72 |
| $10^3$ | 74 |
| $10^4$ | 76 |

| Frequency f, Hz | $SPL L$, dB |
|----------------|-------------|
| $10^2$ | 78 |
| $10^3$ | 80 |
| $10^4$ | 82 |

| Frequency f, Hz | $SPL L$, dB |
|----------------|-------------|
| $10^2$ | 84 |
| $10^3$ | 86 |
| $10^4$ | 88 |

| Frequency f, Hz | $SPL L$, dB |
|----------------|-------------|
| $10^2$ | 88 |
| $10^3$ | 90 |
| $10^4$ | 92 |

| Frequency f, Hz | $SPL L$, dB |
|----------------|-------------|
| $10^2$ | 92 |
| $10^3$ | 94 |
| $10^4$ | 96 |

| Frequency f, Hz | $SPL L$, dB |
|----------------|-------------|
| $10^2$ | 96 |
| $10^3$ | 98 |
| $10^4$ | 100 |
When sound field in a room cannot be considered as diffuse, both direct $E_d$ and reverberative $E_r$ components of (1) should be taken into account. Passing to the geometrical approach of sound field consideration with a source in a room, we have:

$$ E = E_d + E_r = \frac{W}{c_0} \left( \frac{B + 16\pi r^2}{4\pi r^2 B} \right) $$

(9)

Using (5) turn to SPL:

$$ L = 10 \log \left( \frac{2pc_0}{p_0^2} \left( \frac{B + 16\pi r^2}{4\pi r^2 B} \right) \right) $$

(10)

Therefore we have SPL reduction $\Delta L = L_1 - L_2$ expressible as:

$$ \Delta L = 10 \log \left( \frac{B_2}{B_1} \left( \frac{B_1 + 16\pi r^2}{B_2 + 16\pi r^2} \right) \right) $$

(11)

**Calculation**

Calculated SPL reduction $\Delta L_{R_1}$ for each point $R$ by formula (11) compared to measurement results $\Delta L_{R_{meas}}$ shown at Figures 11-15.

Calculated SPL reduction $\Delta L$ averaged over all points by formula (11) (Variant 2. Calculation in view of source distance) and calculation results by formula (8) (Variant 1. statistical approach), compared to measured reduction $\Delta L_{meas}$ are shown at Figure 16. It is seen from graph that calculated and measured data coincide within the limits of experimental error (precision around 1 dB). Calculation result could be considered to be correct.

**Figure 11.** Calculated SPL reduction $\Delta L_{R_{01}}$. Variant 2 (calculation in view of distance)

**Figure 12.** Calculated SPL reduction $\Delta L_{R_{02}}$. Variant 2 (calculation in view of distance)
Conclusions

1. SPL reduction calculation results by method [1] correlates well with laboratory measurements both with statistical approach to sound field (Variant 1) and with source distance consideration (Variant 2).

2. Calculation by Variant 2 shows slightly better correspondence with measured data in the midfrequency range.
3. Calculation method [1] of SPL reduction in rooms suggested by present authors allows to estimate desired sound level change due to carrying in known amount of additional absorption. The method may be applied in acoustic calculations at different stages during design of new or reconstructed halls of various applications.

4. Under complicated configuration of sound field (e.g. poor diffuseness in a room; having few sound sources of equal power) it can be modeled with point sources of fitted acoustical power as shown in [1]. With such a simulation contribution of each source in summary SPL can be estimated in every point by formula (10), SPL reduction of each component is obtained from formula (11), therefore resultant SPL reduction can be calculated.

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