Impedance measurement of materials by use of ambient noise for computational acoustics

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ABSTRACT

Although various kinds of computational methods have been developed and utilized in many fields on acoustics, there exists only an insufficient amount of database of normal impedance of boundary materials. To overcome the situation, some of the authors proposed an efficient method in former papers that uses two-microphones, pp-sensor, and ambient noise to measure normal impedance of materials \textit{in-situ}. The purpose of this paper is to give a further validity of the method that utilizes ambient noise by comparing the results obtained by the method with pp-sensor and by one with pu-sensor, or particle-velocity sensor "Microflown" combined with a miniature microphone. First, the basic characteristics of the pu-sensor were measured, and the validity of the particle velocity measured by the pu sensors with the authors' calibration procedure were confirmed in the frequency ranging from 100 Hz to 1500 Hz. Second, absorption coefficients of a glass wool measured by the method with both sensors in a reverberation room were compared. Finally, an example finite element computation of a sound field in a reverberation room by help of the measured impedance values was carried out to give satisfactory agreements.

1 INTRODUCTION

Computational methods to analyze and/or predict sound fields have been developed and utilized widely in these days\cite{1, 2}. In the methods, when they are based on the wave acoustics theory, surface impedance is generally utilized to model absorptive boundaries. There can be found, however, only insufficient amount of impedance database, especially for the use of sound field analysis of a practical architectural room.

To measure material absorption characteristics including impedance, numerous methods have been proposed. Some of the authors gave a short review on the conventional methods and proposed a new one that utilizes ambient noise, or "Environmental Anonymou\textit{\textsuperscript{a}} Noise," to overcome the difficulties of the former conventional methods when they are practically applied in an architectural room, \textit{i.e. in-situ}\cite{3}. For short, let us call the method "EA-Noise method," hereafter in this paper.

On the other hand, to measure particle velocity directly, de Bree has developed a new sensor, Microflown\cite{4}. Very recently, he has also proposed two methods to measure impedance by use of the new sensor, pu-sensor, that consists of Microflown and microphone, and from the reference\cite{6}, further confirmation seems to be undergoing\cite{5, 6}.

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Figure 1: A schematic drawing of the basic setup for EA-Noise method.

The authors have also tried to utilize the pu-sensor in EA-Noise method to compare the measured results with those by two microphones, or pp-sensor. Prior to detailed investigations, a refinement of calibration system by use of Kunt-tube was conducted and basic characteristics of pu-sensor were measured.[7]

Then, the purpose of this paper is to show how the accuracy is when the impedance measured in-situ is applied onto a finite element (FE) sound field analysis of a practical room. A series of impedance measurement was conducted by use of EA-Noise method with both pp- and pu-sensors, and with the impedance data, dissipation matrix in the FE-analysis was constructed for the sound field analysis. In the following sections, outline of the measurement including the basic characteristics of pu-sensor is described shortly first, and the results of trial FEM computations with measured impedance by EA-Noise method are given.

2 IMPEDANCE MEASUREMENT METHOD

2.1 EA-Noise Method; Outline

The method allows simple and efficient in-situ measurements of absorption characteristics of materials in a diffuse field. The authors have examined its repeatability and applicability in several practical environments[3]. The measured impedance by the method can be regarded as a kind of ensemble-averaged quantity at/around a point similar to what Nocke called "effective impedance" in reference[8].

Figure 1 illustrates the basic setup for EA-Noise method using two microphones, i.e. pp-sensor, with equation (1),

$$Z_{EA} = \rho c \frac{H_{ab,EA}(\omega)(1 - e^{2jk(l+d)}) - e^{jk}(1 - e^{2jkd})}{H_{ab,EA}(\omega)(1 + e^{2jk(l+d)}) - e^{jk}(1 + e^{2jkd})}$$

(1)

Here, $H_{ab,EA}$ denotes transfer function between the sound pressures at microphone, a and b, under EA-Noise condition, and $c$, $j$, $k$, $\rho$, and $\omega$ denote speed of sound, $\sqrt{-1}$, wave number, air density, and angular frequency, respectively.

When sufficient amount of EA-Noise exists, a measurement can be conducted successfully. If not, the authors also proposed "pseudo-EA-Noise method," or pEA-Noise method, using some supplemental sound source(s) to improve the condition[9]. For ex-
ample, in an ordinary anechoic room or a reverberation room, EA-Noise method is not easy to be conducted because of insufficient S/N ratio, while pEA-Noise method has been successfully applied in rather quiet rooms including a reverberation room.

2.2 EA-Noise Method; with pu-sensor

In the methods utilizing two microphone technique, spacial difference of the microphone gives the differentiation of incident and reflected wave possible; and other related quantities like acoustic intensity or particle velocity can be derived, too. The distance between the microphones is restricted by the size of microphone diaphragm and comparably larger distance than wavelength usually contributes better accuracy.

The particle velocity sensor, u-sensor, also utilizes the differentiation between two heated-wires and the distance between the wires is relatively small enough comparing with the acoustic wavelength. Then, particle velocity at a point can be expected to be measured, while its basic characteristics as a sensor must be clarified in advance.

When a u-sensor is applied to a surface impedance measurement, its directivity plays an important role. On a catalogue of Microflown, one can find a simple figure of the directivity with an explanation saying that “it shows 8-figure directivity, or cos $\theta$ law,” and we measured the frequency and spacial characteristics of it in detail. The results at 250 Hz and 1k Hz are given in Fig.2 with the section view of pu-sensor. Similar directivity could be confirmed up to 8 kHz. While, omnidirectional directivities were found in the y-z plane as well as in all the three planes of p-sensor.

Then, if a pu-sensor is applied to EA-Noise method instead of pp-sensor, it can be located at the same position of $M_b$ in Fig. 1. Surface impedance of a material is simply defined as

$$Z_{pu} = \frac{p}{u}$$

(2)

where $u$ and $p$ are normal particle velocity and sound pressure at the material surface respectively. They can be estimated with measured particle velocity and sound pressure,
Figure 3: Reverberation room with absorptive material to be analyzed. □W₁W₂W₃W₄ is a pit for sample mounting. (Oita University, V = 168 m³)

\(\hat{u}\) and \(\hat{p}\), on the consideration of distance \(d\), when the u-sensor’s maximum directivity is set to normal direction to the material surface.

3 SOUND FIELD ANALYSIS OF A REVERBERATION ROOM

3.1 Sound Field to be Analyzed or Measured

The sound fields in an irregularly shaped reverberation room illustrated in Fig.3 were analyzed by the authors’ LsFE-SFA, or Large-scale Finite Element Sound Field Analysis[2] using the measured impedance by the above mentioned methods. The computed values are compared with measured ones to discuss the validity of absorbent boundary modeling by use of impedance.

The reverberation room has flat surfaces of concrete except for door and pit for sample mounting on one of the side walls(900 mm × 900 mm, □W₁W₂W₃W₄ in Fig. 3). To change absorptive condition, several samples were installed to the mounting pit in turn. In this paper, a sound filed with one of the samples, glass-wool(32 kg/m³, 50 mm thick) backed by hard wall, is chosen to discuss about in detail.

A sound source is assumed to be located at one FE-element-mesh away from one of the corners on the floor, which is an omnidirectional point source radiating 1/3 octave band noise at the center frequencies of 250 Hz and 500 Hz.

Sound pressures to compare are computed or measured at 294 points on 1.2 m high plane that are illustrated as dots in Fig.3. To conduct closer investigations on the effects of absorptive materials to the sound field, another 187 \((11 \times 17)\) grid-points on the material’s surface were chosen and sound pressure levels were computed and measured on the points.
3.2 Settings of Finite Element Sound Field Analysis

The sound field is computed by use of LsFE-SFA[2]. It is with COCG iterative solver in frequency domain at 2.5 Hz intervals and 1/3 octave band sound pressure levels at the center frequencies of 250 Hz and 500 Hz were summed up.

Acoustic elements employed there were Spl27[10], and complex D.O.F. s are 52,111 for 250 Hz and 219,765 for 500 Hz respectively. Both of them satisfy each requirement for the spacial resolution by the finite element applied.

As is usual in our analysis, an element dissipation matrix, \([C]_e\), is constructed by equation(3) with normal impedance and shape function, \(\{N\}\),

\[
[C]_e = \frac{1}{c} \int_{e'} \rho c \frac{Z_n}{Z_m} \{N\}^T dS.
\] (3)

3.3 Impedance Measurement by pEA-Noise Method

A series of pEA-Noise method was conducted with pp- or pu-sensors to measure impedances of the sample installed to the mounting pit. The mounting condition is the same as what described in the previous section. The measuring points are at the crossings on the 4 × 5 grid over the sample’s surface, and at the center point. Since ambient noise in the reverberation room is too low, six loud-speakers that radiate non-correlational noise were utilized.

As is mentioned above, ensemble averaged impedance at each point can be expected to be measured by EA-Noise method. So, at first, the difference of the absorption characteristics by points are compared in Fig.4. In the measurement, pp-sensor was employed. There, points -1 and -6 are chosen because the distance between them are the longest, and center point is chosen to compare, and small difference by points were found.

In the figure, the values calculated by use of Miki’s empirical equation [11] are also plotted for a reference. An excellent agreement of the values between those of Miki’s empirical equation and those obtained by Kunt’s tube measurement of the material was confirmed in advance.

Figure 5 shows an example of the difference between pp- and pu-sensors, which we regard, at this stage, as not to give so much difference.
4 RESULT OF FINITE ELEMENT SOUND FIELD ANALYSIS

The impedance data obtained in the previous section were applied to LsFE-SFA and results are given in Fig. 6 comparing the sound pressure level distributions on the 294 points. On the whole, computed values agree well with measurement, and not so much difference among the impedances can be found there. It is because that the sample area is too small to give distinct difference in the sound field over the room.

Therefore, closer investigations were conducted on the sound pressure levels at the 187 points over the sample’s surface and the results are shown in Fig. 7. In the figure, "EApu20" means that measured 20 impedance values at each finite element grid point were given to construct $[C]_a$, while "EApuC" means that only the impedance value at the center of the material was given. Both impedances were measured by use of pu-sensor.

At 250 Hz, where wavelength is comparably long, the difference of impedance of the cases does not give so much difference onto the sound field close to the material, while at 500 Hz comparably better approximations can be achieved by use of the measured impedance than that obtained by use of Miki’s empirical equation, but further investigations with the different samples, frequencies, and so on are required and they are now undergoing to confirm the tendency obtained here.

5 CONCLUSIONS

Through the investigations, basic potential of EA-noise method using pp- and pu-sensors were explained. Trial FEM computations on the sound field in a practical reverberation room using both LsFE-SFA and measured impedance data by EA-noise method showed expectable results especially for the computations in higher frequency regions. Further confirmation studies are required and are now undergoing.

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Figure 6: Comparison of 1/3 octave band sound pressure level distributions at 294 points on a 1.2 m high plane (center frequencies of 250 Hz and 500 Hz). LsFE-SFA with 20 impedance values obtained by EA-noise method with pp- or pu-sensors vs measurement. Miki: computation with Miki’s empirical equation.

Figure 7: Comparison of 1/3 octave band sound pressure level distributions at 187 points on the surface of sample material (center frequencies of 250 Hz and 500 Hz). LsFE-SFA with impedances vs measurement. EApu20: computation with 20 impedance data, EApuC: with impedance data at the material’s center, Miki: with Miki’s empirical equation.

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