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MEASUREMENT OF EQUIVALENT ABSORPTION AREA OF ROOMS USING REFERENCE SOUND SOURCES

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1. INTRODUCTION

The equivalent sound absorption area is necessary to be measured in the measurements of sound transmission losses of materials, sound insulation efficiencies of buildings, and sound power levels of sound sources in diffuse sound field. In these measurements, the equivalent sound absorption area is However, the reverberation time measurement needs additional instrumentation is desirable that the equivalent sound absorption area can be obtained only by sound pressure measurement by omitting the reverberation time measurement, especially in the field measurements of sound insulation efficiencies of buildings. For this purpose, two kinds of techniques for the measurement of equipvalent sound absorption area using stationary and impulsive reference sound sources are investigated theoretically and experimentally in this study.

2. DEFINITION OF ACOUSTIC RADIATION FROM STATIONARY AND IMPULSIVE SOUND SOURCES

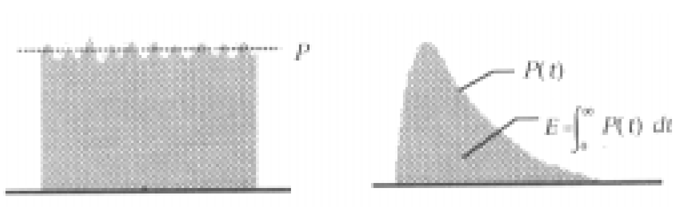

Fig. 1 Definitions of Sound Power and Sound Energy

As is widely recognized, the sound radiation from stationary sound sources is described in terms of "sound power", the sound energy emitted per unit time, or "sound power level" in dB-representation.

Sound power : $P = \overline{P(t)}$ (J/s = W) (1)

$P(t)$: instantaneous sound power, - : time-averaging

Sound power level : $L_W = 10\log(P/P_0)$ $P_0 = 10^{-2}$W

On the other hand, the way of describing the sound radiation from impulsive (transient, in general) sound sources is not clearly defined. Here, Tachibana et al. [1] have proposed a way of describing the sound radiation from transient sound sources in terms of "sound energy" and "sound energy level" as follows (see Fig.1).

Sound energy : $$E = \int_0^\infty P(t)\,dt \qquad (3)$$

Sound energy level : $$L_E = 10\log(E/E_0) \qquad E_0 = 10^{-12}\,\mathrm{J} \qquad (4)$$

Sound energy level can be measured by similar ways as in the measurement of sound power level in a free field or a diffuse field by measuring the time-integrated value of sound pressure or sound intensity instead of measuring the time-average value [1].

3. BASIC EQUATIONS

According to the ways of expression mentioned above, the sound propagation from a stationary or impulsive point source in a free field or a diffuse field can be expressed as follows.

For a stationary sound source in a free field :

$$P = 4\pi r^2 I = 4\pi r^2 \frac{\overline{P^2}}{\rho c} \qquad (5) \qquad\qquad L_W = L_p + 10\log_{10}(r/r_0)^2 + 11 \qquad (6)$$

where, r is the distance from the sound source (m), $r_0 = 1\mathrm{m}$, I is sound intensity $(\mathrm{W/m^2})$, p is sound pressure (Pa), ρc is the characteristic impedance of air, L_W is sound power level of the source (dB), and L_p is sound pressure level (dB).

$$E = 4\pi r^2 \int_0^\infty I(t)\,dt = \frac{4\pi r^2}{\rho c}\int_0^\infty P^2(t)\,dt \qquad (7) \qquad\qquad L_W = L_{pE} + 10\log_{10}(r/r_0)^2 + 11 \qquad (8)$$

where, L_{pE} is sound pressure exposure level

For a stationary sound source in a diffuse field :

$$P = cE_d A/4 \qquad (9) \qquad\qquad L_W = L_p + 10\log(A/S_0) - 6 \qquad (10)$$

where, c is speed of sound $(\mathrm{m/s})$, E_d is sound energy density $(\mathrm{J/m^3})$, and A is equivalent sound absorption area $(\mathrm{m^2})$, and $S_0 = 1\mathrm{m}^2$

For an impulsive sound source in a diffuse field :

$$E = \frac{cA}{4}\int_0^\infty E_d(t)\,dt = \frac{A}{4\rho c}\int_0^\infty P^2(t)\,dt \qquad (11) \qquad\qquad L_E = L_p + 10\log(\mathrm{A/S_0}) - 6 \qquad (12)$$

Here, it should be noted that Eqs. (6) and (8), and Eqs. (10) and (12) are in completely identical form, respectively.

4. MEASUREMENT OF EQUIVALENT SOUND ABSORPTION AREA LEVEL

Ordinarily, the equivalent sound absorption area of a room is obtained by measuring reverberation time, based on the Sabine's equation, as follows.

$$A = 0.162\,V / T \tag{13}$$

$$L_{ab} = 10\log(A/S_0) = 10\log(V/V_0) - 10\log(T/T_0) - 8 \tag{14}$$

where, L_{ab} is equivalent sound absorption area level (dB), V is volume of room (m^3), $V_0 = 1\mathrm{m}^3$, T is reverberation time in the room (s), and $T_0 = 1\mathrm{s}$

Instead of this method, L_{ab} can also be obtained by using a stationary sound source or an impulsive sound source according to Eqs. (10) and (12). That is,

$$L_{ab} = L_{\mathrm{W}} - \overline{L_{\mathrm{p}}} + 6 \tag{15}$$

$$L_{ab} = L_{\mathrm{E}} - \overline{L_{\mathrm{pE}}} + 6 \tag{16}$$

where, $\overline{L_{\mathrm{p}}}$ is the mean sound pressure level in the room (dB), $\overline{L_{\mathrm{pE}}}$ is the mean sound pressure exposure level in the room (dB)

When a stationary sound source is used, the spatial average of sound pressure level is measured, and when an impulsive sound source is used, the spatial average of sound pressure exposure level is measured. In these measurements, L_{W} of the stationary sound source and L_{E} of the impulsive sound source must be of course calibrated in advance of the measurement.

The consideration mentioned above is based on the assumption of an ideal diffuse sound field, but in the case of estimating the mean sound energy density from the sound pressure in actual measurements the correction term $+10\log_{10}(1+S\lambda/8V)$ (the Waterhouse correction, λ : wavelenght, : room surface, : room volume) should be added to and

5. EXPERIMENTAL STUDIES

In order to examine the validity and applicability of the methods using a stationary sound source or an impulsive sound source mentioned above, measurements were made in four rooms of different volume and acoustic characteristic.

(1) Calibration of the reference sound sources

In this study, a hemi-omnidirectional sound source system composed of six loudspeakers shown in Fig.2 was used as a reference source. A pink noise and impulse responses of 2-octave-band filters were radiated from it as a stationary source signal and impulsive ones, respectively. In advance of the field measurements, L_{W} and L_{E} of this sound source were calibrated in a reverberation room of $220\,\mathrm{m}^3$ volume and 6.1 s reverberation time (500 Hz) according to Eqs. (10) and (12). The calibrated sound power levels and sound energy levels in octave bands from 125 Hz to 4 kHz of the reference sound source are shown in Table 1. In these calibration measurements, reverberation time was measured by the conventional interrupted-noise method.

Table 1 Sound power level and sound energy level of the stationary and impulsive reference sound sources

Oct. band center freq. [Hz]	125	250	500	1k	2k	4k
Stationary R.S.S. [dB]	103,0	106,4	106,4	102,6	97,9	92,4
Im pulsive R.S.S. [dB]	93,4	98,7	98,7	83,4	76,4	74,7

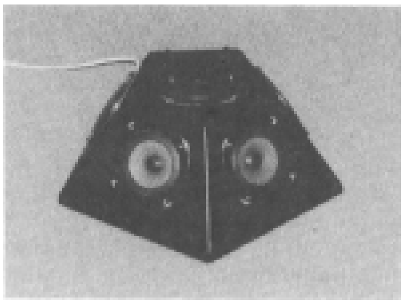

Fig. 2 Reference sound source composed of 6 loudspeakers

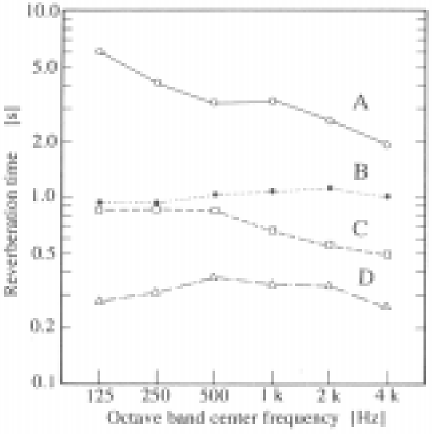

Fig. 3 Reverberation times measured in the four rooms under test

(2) Field measurements

The trial measurements were made in the following four rooms.

A : reverberation room $[V = 220\,m^3, s = 222\,m^2, T = 3.23s\,(500\,Hz)]$
B : reverberation room $[V = 53\,m^3, S = 86.5\,m^2, T = 1.03s\,(500Hz)]$
C : meeting room $[V = 127\,m^3, S = 169\,m^2, T = 0.84s\,(500Hz)]$
D : TV control studio $[V = 184\,m^3, S = 235\,m^2, T = 0.37s\,(500Hz)]$

In these measurements, the conventional method measuring reverberation time by the interrupted noise method was also preformed in addition to the two kinds of reference sound source methods. In order to avoid the changes of sound power level and sound energy level of the reference source caused by the boundary effect, the sound source system was located on the floor being kept more than 1.5 m away from any of the room boundaries other than the floor [2]. Through all measurements, the sound source was located at a point and six receiving points were distributed in the far field from the sound source in the receiving room. $\overline{L_p}$ and $\overline{L_{pE}}$ were obtained as the energy-mean values of the sound pressure levels and sound pressure exposure levels, respectively, measured at these receiving points.

The reverberation times measured in the four rooms are shown in Fig.3. The room **A** is a rectangular reverberation room equipped with suspended reflectors and has the longest reverberation time among the all rooms tested in this study. The room **B** is a small rectangular reverberation room of which frequency characteristic of reverberation time is tuned to be flat around 1 s by sound
characteristic of reverberation time is tuned to be flat around 1 s by sound
absorption treatment. The room C is a normal room without any special acoustic

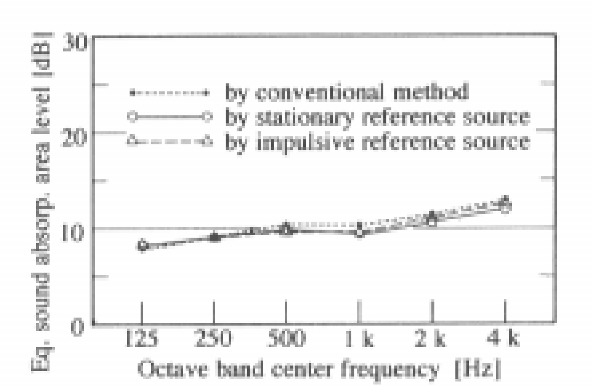

Fig. 4 Measured results for Room A

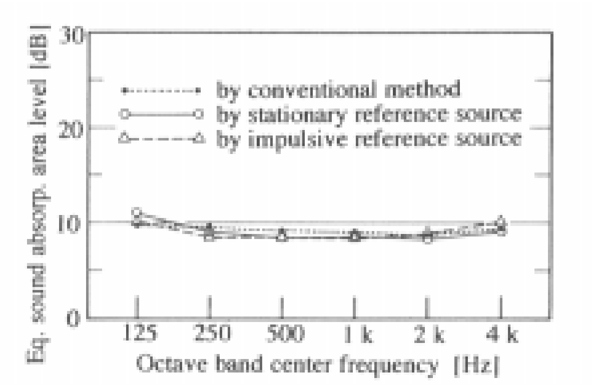

Fig. 5 Measured results for Room B

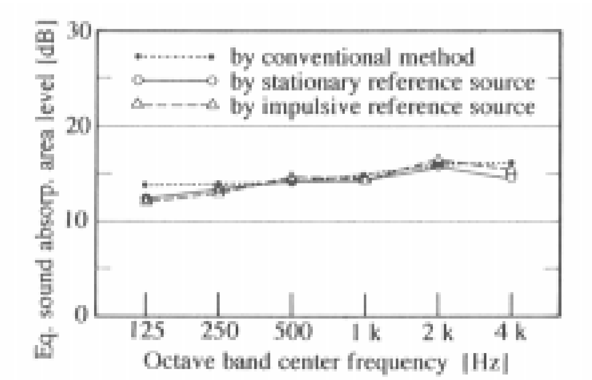

Fig. 6 Measured results for Room C

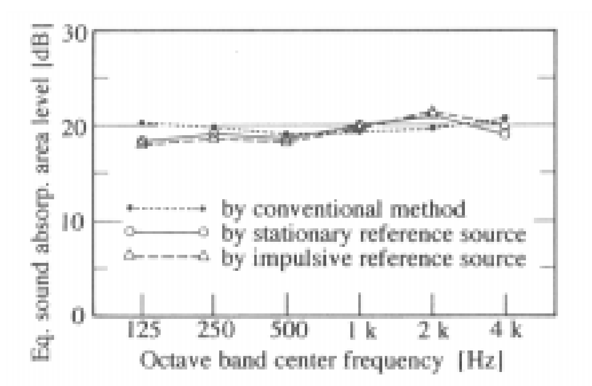

Fig. 7 Measured results for Room D

treatment. The rooms **D** is a studio for the control of TV programs and is much treated with absorptive finishing.

The measurement results of equivalent sound absorption area level for the four rooms are shown in Fig.4 to 7. In the cases of Room **A** and **B**, the results measured by the three different methods are in good agreement within 1 dB. In the case of Room **C**, the agreement of the three kinds of results are fairly good except for 125 Hz and 4kHz bands in which about 1.5 dB differences are seen. In the case of Room **D**, the results measured by the two kinds of reference sound but discrepancies up to 2 dB are seen in 125 Hz and 2kHz bands. These sound field is no longer valid in rooms with rectangular shape, small volume and curves tend to bend and it becomes difficult to determine the reverberation time, especially in low frequency bands.

6. CONCLUSIONS

From the theoretical and experimental investigations mentioned above, we may conclude that the methods using a stationary reference sound source or an impulsive on are effective for the measurement of equivalent can be performed only by sound pressure level or sound exposure level measurement using an integrating-averaging sound level meter and therefore the measurement the reference sound sources must be kept strictly constant.

Regarding stationary reference sound sources, ISO 6926 is now being standardized and they will be effectively used in various acoustic measurements, for example, sound power level determination by the diffuse sound field method (ISO 3741, 3742 and 3743-1, JIS Z 8733). In addition, it is necessary to develop impulsive reference sound sources with enough sound energy, broad band spectrum characteristic and high stability.

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[2] H.Tachibana and H.Yano : Changes of sound power of reference sound sources influenced by boundary conditions measured by the sound intensity technique, Proc. of Inter-noise 89 (1989) p.1009-1012