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ACOUSTIC MEASUREMENTS USING AN IMPULSIVE REFERENCE SOURCE

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1. INTRODUCTION

The method using a time-stationary reference sound source is effective in various measurements in architectural acoustics and noise control engineering. Similarly, the method using impulsive reference sound source is worth considering as an acoustic measurement technique. In this paper, "sound energy level" for an impulsive sound source is firstly introduced as an acoustic quantity corresponding to "sound power level" of a stationary sound source. (The measurement methods of this quantity are described in the Appendix.) Based on the concept, the applications of an impulsive reference sound source to such acoustic measurements as "strength" (sound pressure level distribution in a room), equivalent sound absorption area in a room and sound power level of a sound source are investigated theoretically and experimentally.

2. DEFINITION OF SOUND ENERGY LEVEL L_E

For a stationary sound source, the sound power level L_W is defined as follows (see Fig.1 a).

$$L_W = 10\log_{10}(P/P_0) \qquad (1)$$

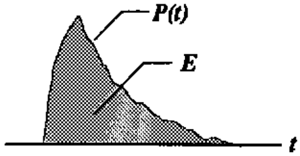
where P is the sound power radiated from a stationary sound source in W, and P_0 is the reference sound power (10^{-12} W).

In order to definitely represent acoustic output of an impulsive sound source referring to the definition of sound power level, we proposed the following "sound energy level" L_E [1] (Fig.1b).

$$L_E = 10\log_{10}(E/E_0) \qquad (2)$$

where E is the sound energy of a single

(a) Stationary sound source



(b) Impulsive sound source

Fig.1
Sound power and sound energy

event of an impulsive sound source in J and E_0 is the reference sound energy (10^{-12} J). The measurement methods of L_E is described in the Appendix of this paper.

3. APPLICATIONS

Measurement of Sound Pressure Level Distribution in a Room

As an important room acoustic characteristic, sound pressure level distribution is measured by various methods, and the following quantity, "strength" G, measured by using an impulsive sound source is proposed in ISO DIS 3382.

$$G = L_{pE} - L_{pE,10} \qquad (3) \qquad\qquad L_{pE} = 10 \log_{10}\left[\frac{1}{T_0}\int_0^{\infty} \frac{p^2(t)}{p_0^2} \cdot dt\right] \qquad (4)$$

where L_{pE} is the sound pressure exposure level measured at an observation point, $L_{pE,10}$ is that measured at a point 10 m apart from the sound source in free field condition and p_0 is the reference sound pressure (20μPa). In practice, however, it is rather difficult to measure $L_{pE,10}$ accurately in field measurement, being influenced by reflections. For this purpose, it would be better to measure the sound pressure level L_p by using a stationary reference sound source with calibrated sound power level L_W or to measure the sound pressure exposure level L_{pE} by using an impulsive reference sound source with calibrated sound energy level L_E. According to the methods using these reference sound sources, G is expressed as follows.

$$G = L_p - L_W + 31 = L_{pE} - L_E + 31 \qquad (5)$$

Figure 2 shows an example of the distribution of G measured in a hall with 1500 seat capacity. In this measurement, a dodecahedral loud speaker was used and pink noise and impulse response of a two-octave-band filter were radiated as a stationary sound source and an impulsive sound source, respectively. The values of L_W and L_E of the sound source were calibrated in a reverberation room in advance of the field measurement. (In the measurements mentioned below in this paper, these reference sources were used.) In Fig.2, it can be seen that the results measured by the two methods are in good agreement.

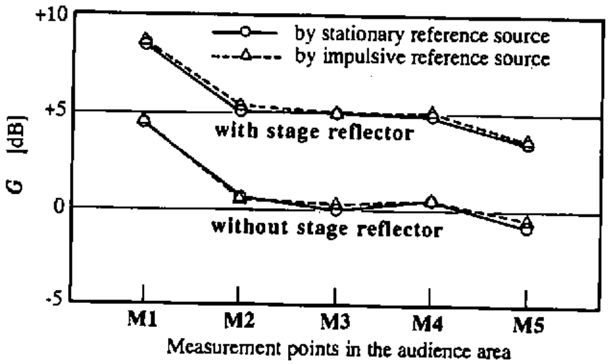


Fig.2 G values in a concert hall (1500 seats) measured by the two reference source methods

As a way of representing sound pressure level distribution in halls measured by using a stationary reference sound source, we have been taking the following way of expression.

$$L_{pn} = L_p + (100 - L_W) \qquad (6)$$

where L_p is the sound pressure level actually measured by using a reference sound source with sound power level of L_W. That is, L_{pn} is the sound pressure level when the sound power level of the source is assumed to be 100 dB. There exists the following relationship between G and L_{pn}.

$$G = L_{pn} - 69 \qquad (7)$$

Measurement of Equivalent Sound Absorption Area in a Room

In the measurement of equivalent sound absorption area in a room, the method of measuring reverberation time is usually adopted. As an alternative method, we examined the method using a stationary reference sound source with calibrated L_W and measuring mean sound pressure level $\overline{L_p}$ in the room under test [3]. Further, this measurement can be made by using an impulsive reference sound source with calibrated L_E and measuring sound pressure exposure level $\overline{L_{pE}}$. According to these reference source methods, the equivalent sound absorption area level L_{abs} (in dB, re. 1 m^2) is expressed as follows.

$$L_{abs} = L_W - \overline{L_p} + 6 = L_E - \overline{L_{pE}} + 6 \qquad (8)$$

Figure 3 shows an example of L_{abs} measured in a meeting room of 127 m^3 air volume by the ordinary reverberation time method and the stationary and impulsive reference source methods. As shown in the figure, the results obtained by the three methods are in good agreement within 1 dB difference. According to these two kinds of reference source methods, L_{abs} can be determined only by using a sound level meter. This point is very advantageous especially for the assessment of room sound absorption in the measurements of sound insulation according to ISO 140 series.

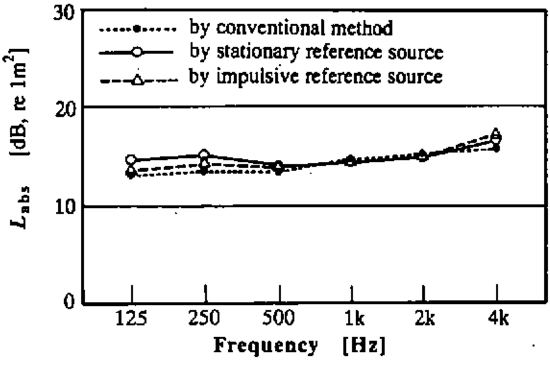


Fig.3 Equivalent sound absorption area level L_{abs} in a meeting room (127m^3) measured by the three methods

Measurement of Sound Power Levels of Sound Sources

For the sound power level measurement, the reference source method (sound source substitution method) is very convenient and is specified in ISO 3747 and JIS 8733 and 8734. Based on the same principle as mentioned above, sound power level measurement can be made by using an impulsive reference sound source. In these reference source methods, the sound power level of a stationary sound source is expressed as follows.

$$L_W = L_{W0} + (\overline{L_p} - \overline{L_{p0}}) = L_E + (\overline{L_p} - \overline{L_{pE}}) \qquad (9)$$

where L_W is the sound power level of the source under test, L_{W0} is that of the stationary reference source, L_E is the sound energy level of the impulsive reference source, $\overline{L_p}$ is the mean sound pressure level by the sound source under test, $\overline{L_{p0}}$ is the mean sound pressure level by the stationary reference source, and $\overline{L_{pE}}$ is the mean sound pressure exposure level by the impulsive reference source.

As a model experiment, the sound power level of a loudspeaker-type sound source (B&K 4205) was determined by the two kinds of reference source methods in the meeting room mentioned above. In Fig.4, the results are compared with the values determined according to ISO 3741 (reverberation room method). The results by these three methods are fairly in good agreement.

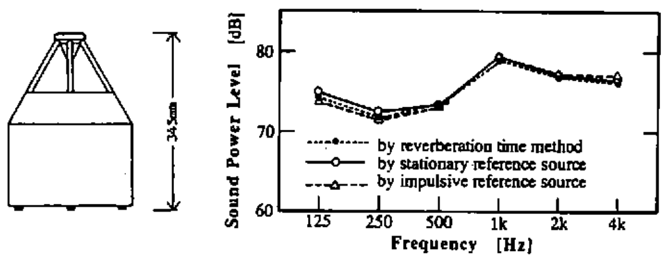


Fig.4 Sound power level of a loudspeaker-type sound source (B&K 4205) measured by the three methods

4. CONCLUSIONS

In this paper, "sound energy level" L_E has been introduced to define the acoustic output of impulsive sound sources. As the application of this quantity, three kinds of acoustic measurements by using an impulsive reference source have been made, and it has been found that impulsive excitation is useful as well as stationary excitation in acoustic measurements. To establish this method, it is necessary to develop impulsive sound source with ideal time and frequency characteristics, stability and convenience.

References

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APPENDIX
(Measurement of sound energy level L_E)

The sound energy level L_E of an impulsive sound source can be determined in the similar ways as in the determination of sound power level of a stationary sound source as follows [1,2].

(A) The Sound Pressure Method in Free Field Condition

Let us consider the time-integrated value of the sound intensity (J/m^2) expressed as follows and call it "sound intensity exposure".

$$e = \int_0^\infty I(t) \cdot dt \qquad \text{(A1)}$$

In the far field of the sound source $I(t)$ is in proportion to $p^2(t)$, and e can be expressed as

$$e = \frac{1}{\rho c}\int_0^\infty p^2(t) \cdot dt \qquad \text{(A2)}$$

Here, we define "sound intensity exposure level" as follows.

$$L_e = 10\log_{10}(e/e_0) \qquad \text{(A3)}$$

By assuming the reference value of sound intensity exposure e_0 as

$$e_0 = \frac{E_0}{S_0} = I_0 \cdot T_0 = \frac{p_0^2}{\rho c} \cdot T_0 = 10^{-12}\ (\mathrm{J/m^2}) \qquad \text{(A4)}$$

where $I_0 = 10^{-12}$W, $T_0 = 1$ s, and $S_0 = 1$ m^2, the following expression is derived from eqns.(A2) and (A3).

$$L_e = 10\log_{10}\left[\frac{1}{T_0}\int_0^\infty \frac{p^2(t)}{p_0^2} \cdot dt\right] = L_{pE} \qquad \text{(A5)}$$

where L_{pE} is "sound pressure exposure level" defined by eqn.(4). That is, L_e is equivalent to L_{pE} according to the definition mentioned above.

In case where a spherical measurement surface of radius r is assumed, the total energy is $E = \bar{e} \cdot 4\pi \cdot r^2$, where $\bar{e}$ is the mean value of e on the measurement surface. Hence, L_E of the impulsive sound source is expressed as follows.

$$L_E = 10\log_{10}\left(\frac{E}{E_0}\right) = 10\log_{10}\left(\frac{\bar{e} \cdot 4\pi \cdot r^2}{e_0 \cdot S_0}\right)$$
$$= \overline{L_e} + 10\log_{10}\left(\frac{r^2}{r_0^2}\right) + 11 = \overline{L_{pE}} + 10\log_{10}\left(\frac{r^2}{r_0^2}\right) + 11 \qquad \text{(A6)}$$

where $\overline{L_{pE}}$ is the energy-mean value of L_{pE} over the spherical measurement surface and r_0 is the reference length (1 m). That is, $\overline{L_{pE}}$ of an impulsive sound source can be determined by measuring the mean sound pressure exposure levels L_{pE} on the measurement surface. (In case where the measurement is made on a reflective plane in hemi-free field, 11 in eqn.(A6) must be substituted by 8.)

(B) The Sound Pressure Method in Diffuse Field Condition

In case where a transient sound source is located in a diffuse field (reverberation room), the following energy-base equation holds true.

$$P(t) = V \cdot \frac{dE_d(t)}{dt} + \frac{c \cdot E_d(t)}{4} \cdot A \qquad \text{(A7)}$$

or

$$\int_0^t P(t) \cdot dt = V \cdot E_d(t) + \frac{c \cdot A}{4} \int_0^t E_d(t) \cdot dt \qquad \text{(A8)}$$

where $P(t)$ is the instantaneous sound power (W) emitted by the source, $E_d(t)$ is the sound energy density (J/m^3) in the reverberation room, V is the air volume (m^3) of the room and A is the equivalent sound absorption area (m^2) of the room.

In eqn.(A8), $E_d(t)$ becomes zero by making $t \rightarrow \infty$, and the total sound energy of a single event of the impulsive source is expressed as follows.

$$E = \int_0^\infty P(t) \cdot dt = \frac{c \cdot A}{4} \int_0^\infty E_d(t) \cdot dt \qquad \text{(A9)}$$

Here, the following equation is valid in a diffuse field.

$$E_d(t) = p^2(t) / \rho c^2 \qquad \text{(A10)}$$

Hence, eqn.(A9) can be expressed as

$$E = \frac{A}{4\rho c} \int_0^\infty p^2(t) \cdot dt \qquad \text{(A11)}$$

Consequently, L_E can be expressed as follows.

$$L_E = L_{pE} + 10 \log_{10}(A/S_0) - 6 \qquad \text{(A12)}$$

As mentioned above, the sound energy level L_E of an impulsive source can be determined by measuring sound pressure exposure level L_{pE} and equivalent sound absorption area A in a reverberation room.

(C) The Sound Intensity Method

As in the case of determining sound power level of a stationary sound source, the sound intensity technique can be used in determining L_E of an impulsive sound source. That is, the total sound energy can be obtained by measuring instantaneous normal sound intensity on the measurement surface enveloping the sound source and by calculating the sound intensity exposure e as the time-integrated value of sound intensity, and further by integrating the value of e over the whole measurement surface.