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MEASUREMENT OF REVERBERATION TIME BASED ON THE DIRECT-REVERBERANT SOUND ENERGY RATIO IN STEADY STATE

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Introduction

Generally it is natural to carry on the sound field in a room in view of the energy ratio between the direct sound and the reverberant one. Concepts of noise reduction based on absorption treatment are founded on the similar situation. Here the sound energy in a room is considered to be a sum of the direct sound energy which is in proportion to inverse square of the distance between source and receiver and the reverberant one which distributes uniformly in a room. Until now there are very few reports which discuss about the diving those two components. Then we consider a method to measure the energy ratio of the direct-reverberant sound using correlation technique. As an example, we applied this method for the measurement of reverberation time.

1. Energy ratio of the direct-reverberant sound

1-1. Principle

The energy ratio of the direct-reverberant sound at a point in a room separated r(m) from a source is described as a ratio of the direct mean square sound pressure and the reverberant one:

$$k = P_d^2(r) / P_r^2 \qquad (1)$$

It is difficult to measure k directly from energy bases, but from wave form by means of a property of time correlation. Generally in a case as sounds radiated from source arrive at a receiver through distinct transmission path, the correlation function of delayed source signal and receiver one equals a pressure contribution of a transmitted sound from source[1]. So that regarding the first transmitted sound as a direct one, it is possible to obtain k by means of simple transformation.

Here using $s(t)$ for the source signal, the receiver signal can be expressed by means of next equation,

$$m(t) = K \sum_n k_n \, s(t - t_n) \qquad (K = \text{const.})$$

Then diving into two parts: the direct and the reverberant sound,

$$m(t) = k_0 K \, s(t - t_0) + m_r(t) \qquad (2)$$

where k_0, t_0 are pressure contribution and transmission time of direct sound. Now time correlation coefficient can be expressed by means of

$$\phi_{ms}(\tau) = \overline{m(t) \cdot s(t-\tau)} / (\overline{m^2(t)} \cdot \overline{s^2(t)})^{1/2}$$

Substituting $s(t), m(t)$, and $\overline{m^2(t)} = K^2 \overline{s^2(t)}$

$$\phi_{ms}(\tau) = k_0 \cdot \overline{s(t-t_0) \cdot s(t-\tau)} / \overline{s^2(t)}$$

When $\tau = t_0$,

$$\phi_{ms}(t_0) = k_0$$

Here rewriting k_0 in terms of energy

$$k_0 = (P_d^2 / P_d^2 + P_r^2)^{1/2} \quad (4)$$

Combining Eq.(1) and (4), finally k is transformed as follow,

$$k = k_0^2 / (1 - k_0^2) \quad (5)$$

1-2. Diffusivity and Incoherency

In general the frequency region which satisfies the condition of diffusion would be above Schroeder's cut-off frequency; $f_c = 2000(T/V)^{1/2}$. At low frequency region in a usual room this condition would not be held. But in such case the equation mentioned above is still valid. The lack of duffusivity is not an essential restriction, but makes the observational error increase.

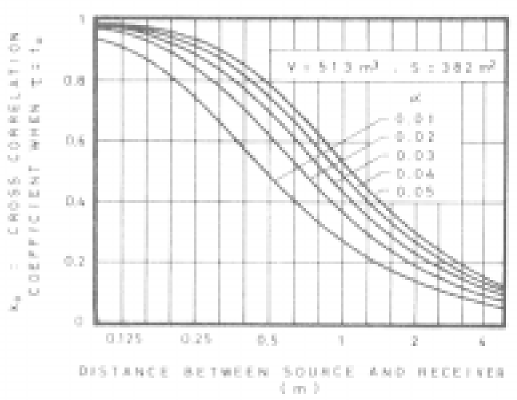


Fig.1 Relation between the pressure ratio of the direct sound to all, k_0 and the distance between source and receiver for various values of absorption coefficient : 0.01-0.05

The incoherency between the direct and the reverberant sound will be held good in the region that the path difference Δd between the direct and the reverberant sound satisfies next relation.

$$\Delta d \geq c / \Delta f$$

where $c, \Delta f$ are sound velocity in the air and frequency band in study. It is necessary to satisfy above condition. Evidently Δd increases as frequency becomes lower and band-width nallower. Regarding the room shape as a spheare, the relation between the volume of room and Δf is

$$\Delta f \geq 274 \cdot \mathrm{V}^{-1/3} \quad (6)$$

2. Application

The important fields of application are as follows;

a) As shown in as earlier papers [2,3], the probability distribution of SPL at any point in a room depends on the energy ratio of the direct and the reverberant sound. So it can be applicable to evaluate the diffusivity of sound field in a room.

b) A product of the reverberant sound energy and k indicates the strength of source. So the contribution of a special noise source in a room would be analysed.

c) The energy ratio of the direct sound to all, which is equal to k_0 squared can be expressed by k . So the radiation power of a noise source may be obtained by means of next equation.

$$W = 4\pi r^2 k 10^{\mathrm{SPL}/10} / \rho c(1+k) \quad (7)$$

Parameters in Eq.(7) will be mentioned in the later section. The estimation of PWL using Eq.(7) is slightly tedious in comparison with that which was proposed by ISO, but dose not need a reverberation time and a correction factor of energy concentration near surfaces.

d) The reverberant sound energy in a room depends on the absorption of a room. Then it is possible to calculate the reverberation time or absorption from the energy ratio of the direct-reverberant sound. In next section, the experimental procedure to measure the reverberation time is described.

3. Measurement of reverberation time

3-1. Derivation of formula

From statistical acoustics the direct and the reverberant mean square pressure are expressed as follows [4],

$$P_d^2 = \rho c Q W / 4\pi r^2, \qquad P_r^2 = 4\rho c W / \mu R$$

where $\rho c, W, Q, r, R, \mu$ are acoustic impedance of the air, power radiated from source, directivity factor, distance between source and receiver, room constant and Waterhouse's correction factor[5]. Inserting those values into Eq.(1), then the reverberation time is expressed as follow,

$$T = (\mu QS + 16\pi r^2 k) / 100\pi r^2 (S/V)k \tag{8}$$

where V, S are the volume and the surface area of a room.

3-2. Optimum distance

Fig.1 shows the relation between r and k_0 for various values of absorption coefficient. It's clearly seen from the figure that the sensitivity is good in some region of r. Then as the condition for getting a optimum distance, it would be suggested that k_0 equals 0.5. Putting $\mu = 1, Q = 1$, the following equation is obtained on referring to Formula(8).

$$r_{\text{opt.}} = (3\alpha S / 16\pi)^{1/2} \tag{9}$$

Where α is the absorption coefficient of a room.

3-3. Measurement

The block-diagram of the facility for measurement in a labolatory scale is shown in Fig.2. A source, connecting a driver unit to one end of a pipe and radiating from another, is nearly a point source. The directivity factors were obtained from the data of SPL in anechoic room. These factors at an angle of 75° nearly equal unity to the frequency of 5kHz. A microphone is almost nondirectional. A frequency converter is used for matching the signals to a time delay devise, utilizing the positional difference of two microphones placed respectively in each acoustic tube. A correlator is an analog type which is set up with a multiplier and a low pass filter[6]. A recorder records correlation functions on a chart. A computer computes a reverberation time according to Eq.(5) and Eq.(8). A reverberation room used[7] is: $V = 513\text{m}^3$, $S = 382\text{m}^2$.

The separation between a point source and a receiver is 0.7m, which is decided from Eq.(9) as $\alpha = 0.02$. Schroeder's cut-off frequency is about 400Hz. As to the condition of incohorency, Δf must be greater than 30Hz. After general consideration, the driving condition of source which is 1/3 Oct. band noise and the frequency range of 125-2000Hz, was decided.

In order to obtain various values of reverberation time, some kind of absorption material (10m^2) were placed on the floor of the reverberation room. A point source and a microphone were hung up at center.

3-4. Results and discussion

To confirm the validity of the consideration mentioned above, the reverberation time was measured from the decay curve. The comparison ration time distributes around the straight line of 45-degree angle. In general, results obtained by two different methods agree fairly well. But those disagree with each other at long reverberation time obtained at low frequency region. In order to clarify this fact, the frequency characteristics of the discrepancy is shown in Fig.4 referring to the results which were measured from the decay curves. Above the frequency of 315Hz it shows a good agreement. It seems to be quite all right to consider that the results obtained from Formula(8) are almost the same as those obtained from the decay curves. From simple estimation the equivalency may be kept more than the frequency of 2kHz. It is satisfactory to consider Schroeder's cut-off frequency as a minimum limitation at low frequency.

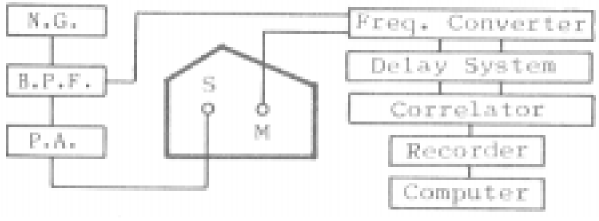


Fig.2 Block diagram of the facility

The main reason for the discrepancy would be in the unsatisfaction of the condition of measurement. The largest cause for the error in this experiment is closely related to the diffusivity of reverberant sound field in a room.

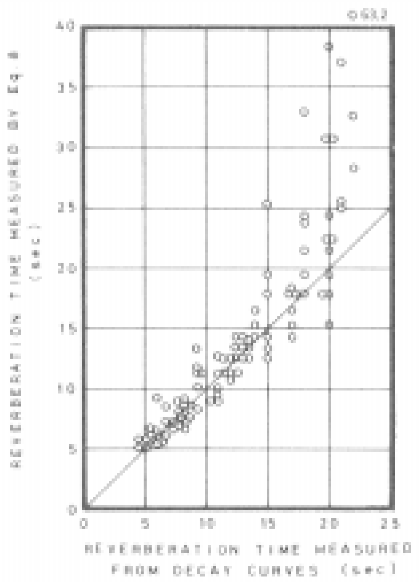
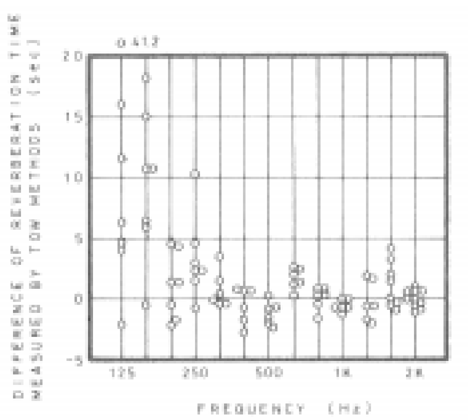


Fig.3 Correspondence of the results which were measured by two methods

Fig.4 Frequency characteristics of the discrepancy of the reverberation time measured by two methods. Points were plotted referring to the results measured from the decay curves



4. Conclusion

The energy ratio of the direct-reverberant sound, one of the important parameter in room acoustics, was derived using time correlation technique. There are many fields of the application and they are briefly mentioned in Section 2. Then the idea of the energy ratio of the direct-reverberant sound was applied to a measurement of reverberation time, and a formula was derived based on statistical acoustics. Experimental data ware obtained in a reverberation room for various values of absorption. The results approximately agree with those obtained from decay curves. Concludingly an obvious quantitative relation between steady state and transient state was confirmed.

Is has been pointing out that the precise measurement of reverberation time is very difficult owing to a unsatisfactory of the condition of measurement or a variety of observer who reads a decay curve [8]. And so these considerations will be a great help in attacking the problem of the improvement of accuracy of measurement and will give us one of general idea of acoustic measurement.

Now data processing is in the improvement stage for practical application. A degital computer will plays an important role, for example, the reduction of the calculation time of correlation function.

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