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RANDOM SOUND FIELD IN REVERBERATION CHAMBERS

BY

C. G. BALACHANDRAN

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Random Sound Field in Reverberation Chambers*

ANALYZED

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A series of experiments were performed to compare the efficiency of different diffusing devices in producing a completely random sound field in a reverberation chamber and the effectiveness of some of the methods for judging whether a sound field is completely random. An additional experiment was performed to compare two types of test signals, *viz.*, warble tone and the same nominal band width of random noise. Results of these measurements indicate the general superiority of the rotating vane over other diffusing devices and superiority of random noise over warble tone in producing a smooth decay curve. One of the significant conclusions is that even when the diffusion is reasonably adequate the measured absorption coefficient of a standard sample appears to vary with the chamber absorption especially at the high frequencies.

INTRODUCTION

THE production of a completely random sound field in a reverberation room is necessary as the formulas of classical reverberation theory are based on the assumption of such a field in the room. These formulas are widely used in the determination of sound absorption coefficient and sound transmission loss of acoustical materials. The absence of randomness restricts the application of the simple reverberation formulas and it has often been found necessary to assume that this probably is one of the causes for disagreement between the values of absorption coefficients reported from various laboratories.

Various methods have been proposed by many investigators in an effort to realize experimentally the complete randomness of sound field assumed in the reverberation theory.¹ Unfortunately, it is difficult to judge the relative merits of these various artifices unless experiments are performed in one chamber utilizing the same experimental techniques for assessing the degree of diffuseness of the sound field in the chamber. Some experiments have been made using scale models,²⁻⁴ but little has been reported on comparative studies in an actual reverberation room.

The aims of this series of experiments were to compare (a) the efficiency of different techniques in producing a random sound field, and (b) the effectiveness of some of the available techniques for judging whether a sound field is completely random. In addition, a subsidiary experiment was performed to compare the standard warble tone sound source and a random noise source in producing a diffuse sound field.

All the experiments were performed in a rectangular chamber 26 by 21 by 16 ft (7.9 by 6.4 by 4.9 m) and

volume approximately 8700 cu ft (250 cu m). Experiments started with a bare room (designated condition 1). Then the following modifications were made to the room to alter the room geometry or otherwise to randomize the sound field: a rotating vane 48 sq ft in area, mounted at a slant of about 30° to the vertical and rotating at the rate of 12 rpm (condition 2); triangular plywood diffusers 8 ft in height and of different dimensions for their sides from 4 ft down to 1½ ft (condition 3); plywood scatterers of different dimensions placed in space (condition 4). Since the diffusers and scatterers necessarily added absorption to the chamber an added series of measurements were carried out with absorbing patches 8 ft high and 2 ft wide suitably spaced and placed against the walls (condition 5). These room conditions were studied with a warble tone source, *i.e.*, a sinusoidal signal frequency-modulated with a sawtooth wave. An additional study was made of the bare room employing a random noise source (condition 6).

The degree of diffuseness of the sound field was evaluated using the following as criteria.

(1) *Precision of reverberation time measurements.*—As a measure of the level fluctuations in decay curves obtained with the various empty room conditions, the quantity σ_T/T where T is the value of the reverberation time and σ_T the standard deviation of the mean value of T , was calculated for all frequencies and room conditions.

(2) *Variation in correlation coefficient with distance between two points in the room.*—This measurement was made for the empty chamber for all room conditions and frequencies up to 2000 cps and compared with the theoretical result for a random field.

(3) *Absorption coefficient of a standard sample of material (72 sq ft) for all room conditions and frequencies.*—This is a direct measure of the suitability of the sound field for reverberation calculations.

EXPERIMENTAL

Reverberation Time and Absorption Coefficient

The reverberation times at the six standard sound frequencies, 125, 250, 500, 1000, 2000, and 4000 cps

* This is a contribution from the Division of Building Research, National Research Council, Ottawa, Canada, and is published with the approval of the Director of the Division.

† On leave from Central Building Research Institute, Roorkee, India.

¹ L. L. Beranek, *Acoustic Measurements* (John Wiley & Sons, Inc., New York).

² P. V. Brüel, *Acustica* 4, 21 (1954).

³ E. Steffen, *Hochfrequentztech. u. Elektroakust.* 67, 73 (1958).

⁴ K. Sato and M. Koyasu, *J. Phys. Society Japan*, 14, 365 (1959).

were measured using the chronograph method for measuring the time of decay. Two hundred such measurements each for a 30-db decay starting after the first 10-db decay were added up. This was repeated 20 times and the standard deviation of the reverberation time from the arithmetic mean of these values was calculated for each frequency and condition of the chamber. In all the reverberation time measurements the test signal was frequency modulated four times a second with a band width of approximately $\pm 15\%$ at low frequencies and $\pm 10\%$ at the middle and high frequencies. The random noise was passed through a $\frac{1}{3}$ octave filter. This was considered to have roughly the same band width as the warble tone, but a subsequent analysis showed that the effective band width of the random noise was wider than the warble tone.

By using these reverberation times, the absorption coefficients of the sample were calculated by employing Eyring's formula. This procedure was considered desirable as there was an appreciable variation in the total absorption in the chamber for the different room conditions. Average absorption in the empty chamber was less than 0.05 at all frequencies and room conditions. Although temperature and humidity were controlled at 70°F and 55% relative humidity, the short-term fluctuations in temperature and/or humidity may have affected the measurements at 4000 cps.

Correlation Coefficients

In a detailed review of the methods for evaluating the diffuseness of a sound field, Furduey⁵ suggests that correlation coefficients for sound pressures between two points in the sound field may be a suitable quantitative measure of the diffuseness of the sound field. A theoretical demonstration of how the correlation coefficient varies with distance between two points has been given by Cook and others.⁶ According to this theory, for a completely random sound field the correlation coefficient is given by $\sin kl/kl$, where k is the wave number ($2\pi/\lambda$) and l the distance between the two points of measurement. The present experimental arrangement for the measurement of this quantity at 125, 250, 500, 1000, and 2000 cps closely followed that of Cook and others.

RESULTS

Some of the correlation coefficient values are presented in Figs. 1 and 2. The solid curve shows the theoretical $\sin kl/kl$ curve and the points are the measured correlation coefficients. To provide a simple basis for comparison the standard deviations (σ_c) of the means of the departures from the theoretical curve for different chamber conditions were calculated. These are shown in Table I. Table II gives the values of sound

FIG. 1. Correlation coefficients for various room conditions.

FIG. 2. Correlation coefficients for two types of test signals.

absorption coefficients of the standard sample for all room conditions and frequencies. Table III gives the ratio of standard deviation of mean reverberation times to the reverberation times (σ_T/T) for different conditions of the empty room.

DISCUSSION

Examination of correlation coefficient and absorption coefficient results (Tables I and II) shows that there is no simple relationship between them. It was finally observed that at high frequencies the absorption results depended mainly on chamber absorption (Fig. 3). It also appears that when σ_c is less than about 0.06, which was generally true in these experiments except at 125 cps, the diffusion is adequate for absorption measurements.

TABLE I. Standard deviation of correlation coefficients from theoretical curve (σ_c).

Room condition	cps				
	125	250	500	1000	2000
1. No diffusers	0.108	0.031	0.036	0.044	0.041
2. Rotating vane	0.053	0.023	0.026	0.010	0.013
3. Wall diffusers	0.014	0.031	0.038	0.033	0.120
4. Space scatterers	0.080	0.053	0.035	0.023	0.024
5. Wall absorbers	0.156	0.029	0.040	0.021	0.023
6. No diffusers (random noise)	0.055	0.022	0.021	0.010	0.019

⁵ V. V. Furduey, Soviet Physics, Acoust. 1, 312 (1955).

⁶ Cook, Waterhouse, Berendt, Edelman, and Thompson. J. Acoust. Soc. Am. 27, 1072 (1955).

TABLE II. Absorption coefficients of a standard sample.

Room condition	cps					
	125	250	500	1000	2000	4000
1. No diffusers	0.06	0.47	1.11	0.67	0.61	0.41
2. Rotating vane	0.16	0.45	1.08	0.75	0.59	0.50
3. Wall diffusers	0.18	0.36	0.77	0.52	0.36	0.35
4. Space scatterers	0.05	0.48	0.86	0.66	0.49	0.31
5. Wall absorbers	0.05	0.38	0.98	0.70	0.36	0.41
6. No diffusers (random noise)	0.16	0.45	0.93	0.68	0.59	0.49

TABLE III. Ratio of standard deviation of reverberation time to reverberation time $(\sigma_T/T)^{100}$.

Room condition	cps					
	125	250	500	1000	2000	4000
1. No diffusers	1.21	0.79	0.40	1.09	1.42	2.10
2. Rotating vane	0.72	0.26	0.46	0.20	0.21	0.36
3. Wall diffusers	0.88	1.10	0.46	0.27	0.31	0.63
4. Space scatterers	0.85	0.46	0.39	0.18	0.28	0.51
5. Wall absorbers	1.10	1.20	0.34	0.27	0.27	0.38
6. No diffusers (random noise)	0.36	0.15	0.16	0.15	0.18	0.26

Measured correlation coefficients for different room conditions indicate that the rotating vane with warble tone as the source produces a satisfactory randomness at all frequencies compared to the other room conditions (1 to 5). This is the usual practice adopted in the chamber at the National Research Council. It was also interesting to find that the random noise source produced a good diffuse sound field in the bare room even in the absence of any diffusing devices in the room. The values of σ_c at all frequencies were found to be less than 0.06 except at 125 cps (one anomalous result at 2000 cps is attributed to experimental difficulties at this frequency).

The absorption coefficient values at 125 cps show a variation corresponding to the degree of diffusion in the chamber as indicated by the correlation coefficients. At this frequency the wall diffusers appeared to be superior

FIG. 3. Absorption coefficient of a standard sample at 2000 cps vs empty chamber absorption.

to the rotating vane as a diffusing agency. A surprisingly good result was obtained even at this frequency with random noise source in the bare room.

Considering conditions 1 to 5, it is evident that the smoothest decay curves are obtained with the rotating vane and warble tone source (Table III). The bare room with warble tone as test signal gave severe fluctuations in the decay curve even at high frequencies. When random noise (albeit a somewhat greater band width) was used in the bare room the results were decidedly superior to all conditions with warble tone at all frequencies. This does not quite agree with the conclusions drawn from similar measurements by Furrer and Lauber,⁷ but it should be noted that in both experiments the percentage band width was not the same for both types of signals at all frequencies. Increased variation of the standard deviation of reverberation time at 4000 cps is probably due to the short-term fluctuations in temperature or humidity.

CONCLUSIONS

(1) Measured absorption coefficients depend on the state of diffusion of the source up to the point where σ_c (standard deviation of the means of the departures of the measured correlation coefficients from theoretical values for a completely random sound field) becomes less than about 0.06.

(2) Even when the diffusion as indicated by the above criterion is adequate, there appears to be a variation of the measured absorption coefficient with chamber absorption. In the present study variations in chamber absorption are inextricably associated with the various diffusing devices. A more detailed study of the effect of chamber absorption alone is now planned.

(3) Fluctuations in the decay curve as indicated by standard deviation of mean reverberation times appear to have little relation to the steady-state diffusion condition in the room. Comparison with the absorption coefficient measurements is slightly better in that at 125 to 500 cps the greatest absorption deviations coincide with the greatest decay curve fluctuations.

(4) All the three types of investigations indicate that random noise passed through a $\frac{1}{3}$ -octave filter is superior to the standard warble tone. The importance of band width with particular reference to random noise is now being investigated more fully.

ACKNOWLEDGMENT

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⁷ W. Furrer and A. Lauber, J. Acoust. Soc. Am. **25**, 90 (1953).