Comparison of hanging panels and boundary diffusers in a reverberation chamber

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ABSTRACT

Achieving a diffuse sound field in a reverberation chamber is crucial for measurements of acoustic quantities such as sound absorption coefficient, scattering coefficient, and sound power level. Toward this aim, diffusing elements such as hanging panels or rotating diffusers are typically installed in the chamber. However, previous research has suggested that hanging panels violate certain theoretical assumptions regarding diffusivity. Also, rotating diffusers cause the chamber to be a time-variant system, precluding the use of some measurement approaches such as sine-sweep integrated impulse response techniques. Boundary diffusers are offered as an alternative in the current study. The effects of both hanging panels and boundary diffusers on sound field diffusivity in a scale reverberation chamber are systematically and comparatively analyzed. The field diffusivity is characterized based on the guidelines set forth in American and international standards, including ISO 354, ASTM C423, and ASTM E90. Resulting data suggests that these standardized methods do not adequately or rigorously quantify diffusivity. The relative effectiveness of hanging diffusers vs. boundary diffusers will be discussed.

1 INTRODUCTION

Acousticians use reverberation chambers to conduct various acoustical tests, including absorption coefficient and scattering coefficient measurements of acoustic materials and surfaces. Each chamber must have a highly reverberant and diffuse sound field, as prescribed by American and international measurement standards. Typically, stationary hanging diffusers and/or rotating diffusers are used in the chamber to help achieve the required diffusivity of the sound field. However, these diffuser types each have potential drawbacks that may limit the accuracy of the measured data. For example, hanging panels cause the actual mean free path length to differ from the theoretical ideal, resulting in absorption coefficient calculation errors. Additionally, rotating diffusers are time-variant, precluding the use of certain measurement techniques such as sine-sweep integrated impulse responses, which have been shown to produce more reliable results with higher signal to noise ratios and lower distortion effects. Furthermore, current reverberation chamber design practices lead to known issues with reproducibility and repeatability of these data. The current study is the first to systematically
study boundary diffusers as an alternative to hanging diffusers, where the effects of each diffuser type are studied in the context of improving reverberation chamber design. Boundary diffusers are defined here as solid forms attached to the interior surfaces of the chamber. (This diffuser type has also been referred to as “volumetric” in the literature. However, there is some ambiguous usage of this term, so boundary diffuser will be used here.)

2 PREVIOUS RESEARCH + MOTIVATION

Specifications for reverberation chamber design have been part of the acoustic literature since the early 1950s, and much of the knowledge documented in the following sixty years has been codified as part of several American and international standards. In general, these standards specify that the chamber have surfaces with relatively low absorption values, a relatively large room volume, and stiff/massive room boundaries, all of which are meant to produce an adequately long reverberation time. Additionally, to achieve a highly diffuse sound field, the standards indicate that the chamber dimension ratios should not be small whole number ratios, and diffusing elements should be installed in the room. To determine the effectiveness of the chamber, sound field diffusivity quantifiers have been developed and are specified in the standards. The current study will focus on the quantifiers given in ISO 354, ASTM C423, and ASTM E90: 1) adequate number of diffusing panels, 2) relative standard deviation of sound decay, and 3) total confidence interval of sound decay and absorption area. These quantifiers are based on sound energy decay and sound pressure level, which can be obtained from impulse response measurements.

Most accredited laboratory chambers use one or more of these quantifiers as a means for verifying the sound field diffusivity in the chamber. However, anecdotal and round robin evidence has shown that inter-laboratory reproducibility of acoustic data is difficult to achieve and high levels of measurement uncertainty remain even when these diffusivity quantifiers are satisfied. This low reproducibility and high measurement uncertainty could be caused by two main factors: 1) sound fields that are not adequately diffuse and 2) divergence of the real chamber from the theoretical ideal as a result of the hanging panel geometry.

Case studies of successful use of boundary diffusers in reverberation chambers can be found in the literature. Additionally, Lautenbach and Vercammen studied a scale model reverberation chamber using three diffusion conditions: with no diffusing panels, with hanging diffusers, and with boundary diffusers. These investigators conducted measurements for several different absorptive test specimens. For all absorptive specimens, they found that the relative standard deviation of decay rate decreased when hanging diffusers were added to the chamber. This standard deviation decreased again when the hanging diffusers were replaced with the boundary diffusers. Their results suggest that the boundary diffusers produce a more diffuse sound field. However, they did not evaluate the diffusers using the two other diffuser quantifiers discussed above. Additionally, they only investigated one configuration of hanging diffusers and one configuration of boundary diffusers. They did not provide a systematic analysis of the number, size, and placement of the diffusers. The purpose of the current study is to carry out this systematic analysis in an effort to more fully understand the difference between the hanging and boundary diffusers and their effect on sound field diffusivity.

3 METHODOLOGY

A scale reverberation chamber (Figure 1) with interior dimensions 1.20 m x 1.50 m x 0.95 m has been used to compare the relative effectiveness of hanging diffusers versus boundary diffusers. All data in this paper are presented in in the real-world equivalent form. Two sound source
positions and eight receiver positions were used. Four types of diffusers, hanging, small boundary, large boundary, and mixed boundary, have been studied. The hanging diffusers are rectangular pieces of slightly curved 1/4-inch plastic, and the boundary diffusers are hemispherical, layered wood, coated with sound reflective varnish. For each diffuser type, a varying number of diffusers was implemented. A maximum of 9 randomly orientated hanging diffusers were used, each with a surface area of 0.21 m² (both sides). A maximum of 51 small boundary diffusers were used, each with a surface area of 0.07 m². A maximum of 22 large boundary diffusers were used, each with a surface area of 0.19 m². The mixed boundary diffusers consisted of both small and large boundary diffusers, with a maximum total of 36 diffusers. The measurement process for each diffuser type began with an empty reverberation chamber with zero diffusers. The number of diffusers installed in the chamber was increased so that the total surface area of diffusers was increased in steps of approximately 0.2 m² for each subsequent configuration. In the results section below, each configuration is designated by a relative surface area, which is calculated as the ratio of aggregate diffuser surface area to total internal surface area of the chamber. Representative diffuser configurations are shown in Figure 1. Impulse response measurements using swept sine signals were taken for each source-receiver combination for each diffuser configuration. The data for the two source positions showed similar trends, so the data for only one source, S1, are discussed here.

Figure 1: Scale reverberation chamber with a) hanging diffusers and b) boundary diffusers

4 RESULTS + ANALYSIS

The impulse response measurement data were analyzed to calculate the results for three sound field diffusivity quantifiers given in ISO 354, ASTM C423, and ASTM E90.15,11,12

4.1 Number of Diffusers

The appropriate number of hanging diffusers is determined based on the absorption coefficient of an absorptive test specimen measured in the chamber with a varying number of diffusers. The specimen absorption coefficient is calculated according to ISO 354 or ASTM C423. Both standards specify that diffusers should be subsequently added to the chamber until the absorption coefficient reaches a maximum value after which it remains constant or drops off as more diffusers are added. This quantifier is predicated on the idea that an adequately diffuse sound field will allow enough sound energy to be incident on the absorber such that a maximum absorption is achieved.

The absorptive specimen absorption coefficient data are shown for each diffuser type as a function of relative surface area in Figure 2. Although this diffusivity quantifier was developed for
hanging diffusers, the method has been applied for the boundary diffusers in the current study as well. The absorption coefficient for the hanging diffusers peaks at 0.95 at a relative diffuser surface area of approximately 14%. The boundary diffuser types achieve a maximum absorption coefficient value of about 0.98 at a relative diffuser surface area of approximately 27%. This result suggests that a relatively diffuse sound field is achieved for all diffuser types, according to the absorption coefficient quantifier. However, each type produces slightly different values of the absorption coefficient. Since the “true” absorption coefficient can’t be known, the results from this quantifier do not allow for the identification of an ideal diffuser type.

![Figure 2](image.jpg)

**Figure 2**: Average absorption coefficient for four diffuser types versus relative surface area

### 4.2 Relative Standard Deviation of Decay Rate

The relative standard deviation of decay rate across receiver position is calculated according to ASTM C423. The standard deviation is normalized based on the average decay rate. Lower values of this relative standard deviation indicate a higher level of sound field diffusivity since a diffuse sound field is, by definition, more homogenous. The standard specifies a maximum value of the relative standard deviation as a function of frequency.

The relative standard deviation of decay rate data are shown as a function of frequency for each diffuser type in Figure 3. Since the standard does not specify which diffuser configuration should be analyzed, the configuration that produced the maximum absorption coefficient as discussed in Section 4.1 was chosen for each diffuser type. The black line in Figure 3 indicates the maximum allowable values according to ASTM C423. None of the diffuser types meet the criteria set forth in the standard across all frequency bands. Although certain diffuser types perform better at specific frequencies, there is not one type that produces consistently lower standard deviation values.
4.3 Total Confidence Interval

The total confidence interval (CI) is calculated according to ASTM E90. CI is dependent on the standard deviation of absorption area of the chamber (without a test specimen) and the
standard deviation of sound pressure level across receiver position. CI estimates the repeatability of the measurements. Lower confidence intervals signify higher degrees of accuracy and precision, and a higher level of sound field diffusivity. The standard specifies a maximum CI value as a function of frequency. This quantifier is similar to the relative standard deviation quantifier discussed above; however, it examines the homogeneity of decay rate and sound pressure.

The CI data are shown as a function of frequency for each diffuser type in Figure 4. Since the standard does not specify which diffuser configuration should be analyzed, the configuration that produced the maximum absorption coefficient as discussed in Section 4.1 was chosen for each diffuser type. The black line in Figure 4 indicates the maximum allowable values according to ASTM E90. All diffuser types meet the CI criteria set forth in the standard, except for the hanging diffusers, which exceed the maximum allowable value at 5000 Hz by a negligible amount. Since none of the diffuser types met the criteria for relative standard deviation, it suggests that the CI quantifier is not as discerning a quantifier.

5 CONCLUSIONS

Three standardized quantifiers of sound field diffusivity were used to determine the effectiveness of four diffuser types, one hanging diffuser and three boundary diffusers. The effect on diffusivity was analyzed for a variety of diffuser configurations. The quantifiers based on absorption coefficient and confidence interval indicate that all diffuser types produce the required sound field diffusivity. The quantifier based on decay rate relative standard deviation shows that the diffusers are not effective across all frequencies. This disparity in the results suggests that the quantifiers do not adequately characterize sound field diffusivity, either individually or in concert.

The data trends are similar for both the hanging diffuser and boundary diffuser types. These results suggest that boundary diffusers are a viable alternative for providing additional diffusion in a reverberation chamber. However, there is no significant evidence that proves that boundary diffusers are a better alternative as suggested in previous work. It is possible that more precise diffusivity quantifiers could be used to more accurately characterize the effects of each diffuser type, and therefore identify a possible preferred diffuser type. Future work could address the development of these quantifiers.

Additional future work could investigate the effect of the shape of the boundary diffusers, since only hemispherical diffusers were analyzed in the current study. Previous work by one of the current authors introduced a resonating boundary diffuser that could be analyzed as part of this work. Furthermore, a comparison of the relative effectiveness of boundary diffusers and rotating diffusers could be carried out. The current authors plan to evaluate all configurations (not just those producing a maximum absorption coefficient) to determine which best meets all three diffusivity quantifier criteria.

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