RECENT MEASUREMENTS OF TOTAL ENERGY DENSITY USING A UNIQUE TRANSDUCER ARRAY

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1.0 INTRODUCTION

Contemporary laboratory test methods determine the sound power of a noise source by sampling the sound pressure in a reverberant field. While these tests allow for a convenient assessment, they falsely assume that either the sound field is ideally diffuse, or that the sampled data adequately represent the average sound pressure in the room. The research of Budhiantho [1], developed theoretical probability density functions for the potential, kinetic, and total energy densities were modeled in a reverberant sound field. These models suggest that the variance of the total energy density is one half that of the potential energy density approximated by the sound pressure in current test methods and such measurements could yield more accurate results. Experiments were conducted to verify these theories and determine the practicality of the technique.

2.0 MODEL

Based o the earlier work of Waterhouse [2], Cooke and Schaede [3] and Lubman [4], Budhiantho derived a statistical model for the potential, kinetic, and total energy distributions in such a reverberant field.

The model states that a component of the velocity vector can be determined from the integral of the pressure gradient in a given direction.

$$v_x = \frac{1}{\rho d}\int (P_x - P_r)dt \qquad (1)$$

With the assumption that the in the case of a diffuse field, pressure magnitudes are Gaussian and performing only linear mathematical operations, the velocity component amplitude is Gaussian as well.

$$|V| = \left(v_x^2 + v_y^2 + v_z^2\right)^{/2} \qquad (2)$$

The vector velocity is the square root of the sum of the components squared. The result is a Maxwell distribution.

The kinetic energy density is proportional to the sum of the squares of the velocity components. The kinetic energy then becomes a Γ-distribution with three degrees of freedom.

Likewise, the potential energy is proportional to the acoustic pressure squared. This yields an exponential distribution, which is a Γ-distribution with one degree of freedom.

The total energy density is then a Γ-distribution with 4-degrees of freedom

3.0 EXPERIMENT

Several generations of total energy density sensors have been constructed, developing from one-dimensional probes to three-dimensional arrays [5,6], but all were limited in their measurement frequency range. In the present study, there were two major modifications to earlier designs to allow implementation in a commercial laboratory setting: capability of broad band response and integration with a typical rotating microphone boom.

This latest array construction is composed of two nested microphone tetrahedrons with a common reference microphone, for a total of seven microphones. The microphone spacing for the smaller tetrahedron is 15 mm while the microphones of the larger array are separated by a 55 mm gap (see Figure 1).

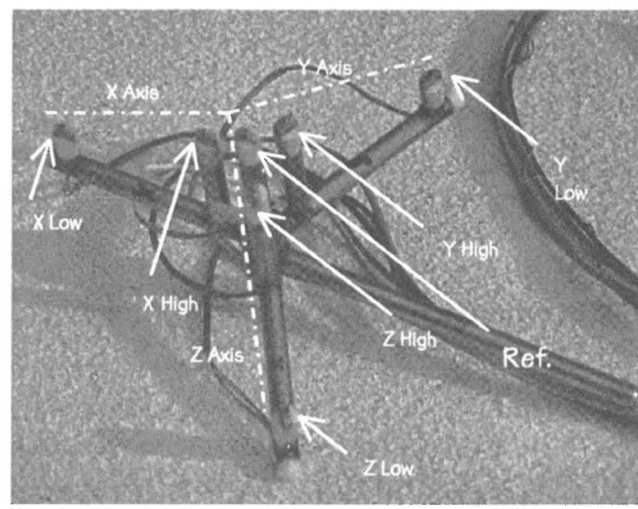

Figure 1: A seven-microphone array for total energy density measurements from 100 to 5000 Hz.

Responses of the arrays are combined in a signal conditioning/amplification module at a crossover frequency of 1000 Hz. This configuration allows the probe to be sensitive in three dimensions with flat response from 100 to 5000 Hz. A second signal conditioning module was added with a third order active low-pass filter to prevent signal aliasing.

Acquisition and processing were executed via LabVIEW processing software on a desktop computer. The processing algorithm sums the pressures to produce an average, then squares it to produce potential energy density. Pressure differences between microphone pairs are integrated to get velocity components, then squared and summed to yield kinetic energy density. Kinetic and potential energy densities are summed to yield total energy density.

Two sound sources were used for the experiments. For pure tones and dual tones, a JBL two-way dynamic driver was excited by a Hewlett Packard function generator. An ILG Industries squirrel cage fan was used as the broad band source.

For each measurement, the sensor was mounted to a 1.6 meter boom and sampled at various fractions of wavelengths along the 10 meter circular traverse. All measurements were conducted in a 319 m3 reverberation chamber qualified to 100 Hz by both ISO and ASTM test methods.

4.0 RESULTS

Experimental results were collected and processed for 26 unique source conditions with signals ranging from 100 to 5000 Hz. The measured standard deviations for 4 representative source configurations are compared to the theoretical standard deviations and are presented in Tables 1 through 3. In addition to tabular results, data was processed as bar chart histograms and showed excellent agreement to theoretical curves. Such graphical comparisons are presented elsewhere.

	Potential Energy Density Norm. Std. Deviation	
Source Configuration	Theory	Measured
Pure tone @ (500 Hz)	1.00	1.02
Pure tone @ (3500 Hz)	1.00	0.99
Dual tone @ (2000 & 2050 Hz)	1.00	1.06
Broad Band Noise	1.00	1.01

Table 1: Standard Deviations of the Potential Energy Density [E_p] for selected measurement conditions

	Kinetic Energy Density Norm. Std. Deviation	
Source Configuration	Theory	Measured
Pure tone @ (500 Hz)	0.57	0.58
Pure tone @ (3500 Hz)	0.57	0.53
Dual tone @ (2000 & 2050 Hz)	0.57	0.60
Broad Band Noise	0.57	0.58

Table 2: Standard Deviations of the Kinetic Energy Density [E_k] for selected measurement conditions

	Total Energy Density Norm. Std. Deviation	
Source Configuration	Theory	Measured
Pure tone @ (500 Hz)	0.50	0.51
Pure tone @ (3500 Hz)	0.50	0.56
Dual tone @ (2000 & 2050 Hz)	0.50	0.56
Broad Band Noise	0.50	0.52

Table 3: Standard Deviations of the Total Energy Density [E_t] for selected measurement conditions

5.0 CONCLUSIONS

Experiments showed that the expanded sensor accurately measured the potential, kinetic, and total energy densities with distributions similar to those predicted by statistical models. In every case, sound power determination using total energy density offered greater accuracy over traditional measurements using potential energy density alone.

Modification allowing continued use of traditional commercial laboratory equipment did not adversely affect the experimental agreement with theory and offered an alternate method for more accurately determining the sound power of sources in reverberation chambers.

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