

inter.noise 2000

*The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE*

I-INCE Classification: 1.2

FURTHER WORK IN SOUND POWER USING TOTAL ENERGY DENSITY MEASUREMENTS

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Keywords:

SOUND, POWER, MEASUREMENTS, LABORATORY

ABSTRACT

A second generation, total energy density probe used to determine sound power was constructed based on the earlier work of Budhiantho and Hixson. The probe was modified to measure a broad frequency range and to be utilized in a manner similar to existing international sound power test methods performed in a reverberation chamber. Improvements in measurement accuracy as implied by the statistical model were investigated for both broadband, narrowband and pure tone noise sources. Considerations for commercial implementation and further work will be discussed.

1 - INTRODUCTION

Contemporary laboratory test methods determine the sound power of a noise source by sampling the sound pressure in a reverberant field. Unfortunately, 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. Earlier research has developed a statistical method for predicting the variability of the pressure in the sound field. Research by Budhiantho [1] developed theoretical probability density functions for the potential, kinetic, and total energy densities. 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 more accurately yield results. Experiments have shown promise for this technique but, to date, no commercially viable solutions exist.

2 - MODEL

Early work to characterize a reverberant sound field beyond that of classical room acoustics was conducted by Waterhouse [2]. He developed a statistical model with the following assumptions: 1) a sufficient number of room modes are energized to satisfy Schroeder's large room conditions

$$f_{sch} = 2000 \cdot T_{60}/V \quad (1)$$

where T_{60} is the reverberation time in seconds and V is the room volume in cubic meters; 2) at any point in the room volume, there is no net power flow; 3) with the above satisfied, the acoustic pressure is a random variable with a Gaussian distribution. Further research by Cooke and Schaede [3] and Lubman [4] established suggested that total energy density in 3-dimensional fields could provide a better estimate of acoustic power.

More recently, 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.

$$\nu_x = \frac{1}{\rho} \int (P_x - P_r) dt \quad (2)$$

With the assumption that the pressure magnitudes are Gaussian and performing only linear mathematical operations, the velocity component amplitude is Gaussian as well.

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

$$|V| = (\nu_x^2 + \nu_y^2 + \nu_z^2)^{1/2} \quad (3)$$

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 - 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 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. 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.

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 - 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, 2 and 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.

Source Configuration	Potential Energy Density Norm. Std. Deviation	
	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.

Source Configuration	Kinetic Energy Density Norm. Std. Deviation	
	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.

Source Configuration	Total Energy Density Norm. Std. Deviation	
	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 - 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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