ERRORS DUE TO SCATTERING EFFECTS IN MULTIPLE MICROPHONE INTENSITY PROBES

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INTRODUCTION

One of the errors of concern in the application of two microphone acoustic intensity meters is scattering from the microphone probe. The primary effect of scattering is to alter the relative phase between the pressure at the two microphone locations. Rasmussen [1] reports that the indicated center-center distance between two adjacent microphones is very sensitive to frequency within the range of interest in intensity measurements. As a result he recommends the use of a face-face microphone mounting arrangement. Both Kiteck [2] and Krishnapa [3] conclude that the majority of the scattering error in practice is due to scattering from the microphone holders rather than from the microphones themselves.

All published literature on the effect of scattering errors on acoustic intensity measurements have been based upon experimental measurements with two microphones in an incident sound field. No reference has been found which provides a theoretical approach for predicting the phase error. Furthermore, the published data normally has been acquired in such a manner that the amount of error in the phase measurement was often of the same order of magnitude as the scattering induced phase shift. This paper reports the results of an improved approach for measuring scattering induced errors. The results are supported by theoretical estimates of the error as good agreement between theory and experiment has been found.

APPROACH

Theoretical Estimates — A theoretical model was developed to estimate the scattering pressures at the centers of two microphones in close proximity to one another. The microphones were modeled as semi-infinite cylinders with a plane wave sound field approaching at a 90° incidence as illustrated in Figure 1. An approximate analytical approach was used in which the higher order scattering effects were ignored. The phase error was determined by first calculating the scattered pressure at the center of microphone B due to scattering from microphone A. Next the scattered pressure at the center of microphone A was determined due to scattering from microphone B. The change in the relative phase between the pressure at microphone A and microphone B was then determined as the scattering induced phase error.
The scattered pressures were only required at points on the R-axis. For points on this axis it can be shown that the scattered pressures for the semi-infinite cylinder are one-half those of the infinite cylinder. The exact expression is given in Equation (1). It should be noted that this model ignores the effect of the end of the cylinder.

\[
p_s(r, \theta) = -\frac{P_l}{2} \sum_{n=0}^{\infty} \frac{\epsilon_n r^n}{H_n'(ka)} J_n' (ka) \left( \frac{H_n (kr)}{H_n'(ka)} \right) \cos n \theta \quad \epsilon_n = 2 \text{ if } n = 0 \quad \epsilon_n = 1 \text{ if } n > 0
\]

Experimental Measurements — In order to improve the accuracy with which the phase errors could be measured it was decided to perform all measurements on large scale models of the microphones. The experimental apparatus is illustrated in Figure 2. Two 31 mm diameter dowels were used to simulate the microphones. The tests were conducted by first measuring the transfer function between two 3/8-inch microphones in the far field of a speaker. The dowels were then placed immediately in front of each microphone and the transfer function again determined. The second transfer function was then divided by the first transfer function. The resulting compensated transfer function (called the scattering function) will be a measure of the magnitude and phase error in the microphone readings due to the microphone scattering effects. The expressions are given below. This test was repeated for various ratios of the separation distance to the dowel radius. The tests were conducted over a frequency range of 0 — 2000 Hz. This would correspond to a frequency range of 0 — 5000 Hz for scaling to a 3/8 inch microphone, and 0 — 10000 Hz for a 3/4 inch microphone.

\[
\begin{align*}
H &= \frac{p_s (\omega)}{p_s (\omega)}; & \text{Scattering Function} \\
TF &= \frac{H_{\text{scattered field}}}{H_{\text{free field}}} 
\end{align*}
\]

The tests were conducted inside of a 4 x 3 x 3 meter anechoic chamber. Initial measurements were taken with a steel floor grating in place within the chamber. These measurements indicated that the scattering effects from the floor were masking the scattering from the test probes. This effect can clearly be seen in Figure 3. The floor scattering effects are the cause of the rapid phase fluctuations at the higher frequencies. These fluctuations were strongly influenced by the position of the probe relative to the sound source. It is interesting to note that the nature of the erroneous scattering results in Figure 3 bear a resemblance to the data reported in various publications discussing microphone scattering effects. These results show that great care must be taken in performing this type of measurement.

RESULTS

The data was acquired for d/a probe spacings of 2, 4, 5, 6, and 8. Typical measured scattering induced phase errors are shown in Figures 4, 5 and 6. These figures show the imaginary part of the measured scattering function. For the majority of the frequency range the magnitude of the scattering function was nearly 1.0. Thus, the phase error may be readily deduced from the figures. Also, theoretical estimates are compared with measured results. It should be noted that the measured results in the lower ten percent of the frequency scale are of questionable accuracy due to the normal limitations of signal processing.

These results indicate that the scattering errors are most severe for d/a = 2 (side by side microphones). The minimum error appears to be with d/a ratios of 6—8. In this evaluation the phase errors for test frequencies above 1000 Hz were not considered, as this would represent scaled frequencies outside the typical application range of intensity probes.
Analysis

points on the R-axis. For points for the semi-infinite cylinder the semi-infinite cylinder pressure is given in Equation of the end of the cylinder.

\[
\begin{align*}
\kappa_n &= 2 \text{ if } n = 0 \\
&= 1 \text{ if } n > 0
\end{align*}
\] (1)

The accuracy with which the phase measurements on large scale is illustrated in Figure 2.

microphones. The tests were between two ¼ inch microphones placed immediately in front of the second transfer function. The resulting compensated values in the magnitude of the microphone scattering effects. The magnitude of the magnitude ratio of the separated microphone over a frequency range of 0 – 5000 Hz for a ¼ inch microphone.

\[
\begin{align*}
\text{scattered field} &= f(x, y) \\
\text{free field} &= f(x, y)
\end{align*}
\] (2)

eter anechoic chamber. Initial distance within the chamber. These measurements were made using a microphone probe placed at the higher frequency position of the probe relative to the source. The results reported in various publications show that great care must be

2, 4, 5, 6, and 8. Typical measurements were 4, 5 and 6. These figures are typical. For the majority of the cases the error was nearly 1.0. Thus, the accuracy of the data was quite good. The results of the theoretical estimates are within 1% of the measured results in the 1/2" microphone. The results are accurate within 1% of the theoretical estimates due to the fact that the most severe for d/a = 2 (side 8 with d/a ratios of 6–8. In fact, 10 000 Hz were not considered because of typical application range of

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These results are summarized in Table 1 with the phase errors for various spacings and frequencies for both quarter and half inch microphones. The results show that for any realistic value of microphone spacing (d) the microphone scattering errors are well within reason over a practical frequency range.

Comparison of the theoretical results with the experimental show there was excellent agreement for the larger microphone spacings (d). The results for d/a = 2 show that the experimental data gave a negative shift, while the theoretical estimate was a positive shift. This large error is likely a result of the compound scattering effects which were ignored by the model. For this spacing the microphone probes are touching; consequently, the compound scattering is expected to be most severe.

CONCLUSIONS

The results of this study clearly indicate that microphone scattering induced phase errors are inconsequential for the majority of intensity probe designs. The only configuration of a side-by-side microphone arrangement which would provide significant phase error would be for a spacing in which the two microphones are touching. This will result in a phase error of +2° in the higher frequencies. While the microphone scattering effects are normally insignificant it should be noted that a poor microphone holder design may induce strong scattering effects.

The experimental approach used in this study has provided suitable methodology for accurately measuring the microphone scattering effects. The experimental results are confirmed by correlation to a simplified theoretical model. The approach outlined here has been used successfully to investigate a four microphone probe design. The results indicate that the probe holder again should be designed properly [4]. Also, mutual scattering effects in such a probe become significant.

REFERENCES


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<th>1/2&quot; Microphone Frequency Hz</th>
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Table 1 – Experimental phase errors scaled to one-quarter and one-half inch microphones.
Fig. 1 – Geometry for theoretical model

Fig. 2 – Schematic of the scattering test arrangement and equipment

Fig. 3 – Scattering function measured with floor grating interference

Fig. 4 – Scattering function measured with d/a = 2.0

Fig. 5 – Scattering function measured with d/a = 4.0

Fig. 6 – Scattering function measured with d/a = 8.0