Reducing Artifacts of In-situ Surface Impedance Measurements

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This paper describes developments of an in-situ measurement system for acoustic surface material measurements. It is based on the generally known 'loudspeaker plus one-microphone' technique whereby the difference of free-field calibration response and surface-reflected response is analyzed. Special attention is paid to signal processing methods in order to minimize artifacts from the acoustic setup and signal analysis (windowing) needed.

INTRODUCTION

In-situ techniques have been developed for some time [1,2], but they are found to exhibit problems that are difficult to overcome. In this paper we propose a number of methods that can improve the results of measurements when using a sound source (loudspeaker) and a microphone near the surface to be measured (Fig.1). When a free-field calibration response $h_r(t)$ is available and the response $h_m(t)$ with a microphone near a surface is measured, the reflected response is $h_m(t) - h_r(t)$. When this is compensated with the reference response, in the frequency domain $H(\omega) = [H_m(\omega)-H_r(\omega)]/H_r(\omega)$, a reflection response is obtained. The surface impedance or absorption coefficient is easily obtained if the reflectance response has been reliably measured. An essential part of the technique is to apply time-domain windowing of the responses in order to exclude reflections from neighboring surfaces as well as diffraction from the edges of the surface of interest.

The method is found sensitive to any degradations of measured responses. Thus most care should be taken to obtain accurate and reliable results. An inherent limitation comes from the time-domain windowing, which restricts frequency-resolution as well, setting a practical low-frequency limit. In this paper we discuss several signal processing techniques for improving this basic in-situ technique.

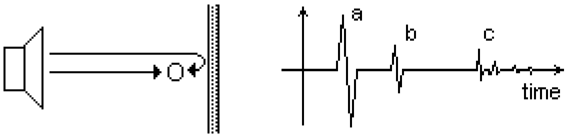

FIG. 1. On the left system setup, on the right an impulse response: a) direct sound b) reflection c) parasitic reflections.

SYSTEM IMPROVEMENTS

The in-situ setup we have developed consists of loudspeaker of spherical enclosure (ø 150 mm), an electret microphone (Sennheiser KE 4-211) 32 cm from the speaker, and a computerized data acquisition system with easy programmability. We have implemented our impulse response measurements using a fast chirp excitation (Schroeder phase sequence) and deconvolution instead of maximum length sequences (MLS), because MLS may yield distorted results when there are nonlinearities in the signal path [3], especially in the loudspeaker. As other minor experiments we tried careful time alignment of the calibration and test direct responses, continuation of the windowed responses by ARMA modeling (Prony's method), and averaging of responses obtained with different microphone distances from the surface. In practice, only minor or no improvements resulted.

Using a hard surface reference

Panel (a) in Fig. 2 plots an example of measured reflection from a surface as well as a time window (rectangular + half of hanning) to cut out parasitic reflections from neighboring walls and edges of the surface to be measured. Panel (b) depicts the result of subtracting the test response and the reference to yield the reflected signal.

Although very carefully measured, the free-field reference (corresponding to peak (a) in Fig. 1) does not yield optimal cancellation in measurement near a surface. In the example of Fig. 2 there was an absorbing material (minearl wool, 20 mm) on a hard wall and the absorption coefficient was computed as a function of frequency. Black squares in (d) indicate the measurement result obtained using impedance tube (B&K

4187) and black circles corresponding data from reverberation room measurement. Thin solid line is the resulting absorption coefficient computed from the in-situ measurement when the reference was measured in pseudo free field and the tested material was in a distance of 6 cm from the absorption material. It is in general agreement with standard techniques above approximately 400 Hz, but below that is entirely unreliable and fluctuates strongly.

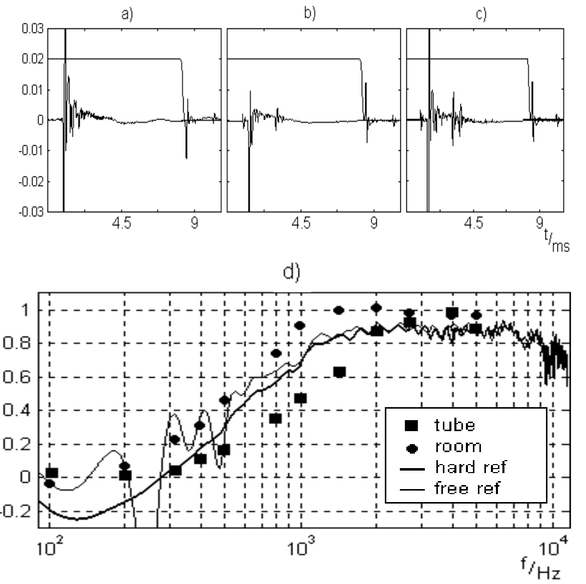

FIG. 2. a) Reference response, b) subtracted reference measurement of absorbing material, c) subtracted hard surface reference of absorbing material, and d) absorption coefficient with four different methods (see text).

As an alternative to the free-field reference, a hard surface reflection was measured and applied. This was achieved by subtracting the free-field response from the hard surface response. Otherwise the measurement technique was similar as mentioned above. The distance to the surface to be measured is kept the same in the hard surface reference measurement and in the material measurement.

As indicated by the thick solid line in Fig. 2, the absorption coefficient behaves more smoothly, although it shows also non-physical negative values at lowest frequences. Especially when the measurement setup is exactly the same for reference and material measurement except that the material is inserted betheen the hard surface and microphone, the method works well (although it is not a generic in-situ method anymore).

Model-based curve fitting

Another way to obtain smooth measurement curves and material parameters is to apply model-based curve fitting. If the general behavior of the material under study is available in the form of a parametric model, (nonlinear) optimization techniques can be used. Figure 3. plots the absorption coefficient of the case discussed above and a model-based fit to the measured data. Fitting was applied to the complex-valued reflectance function as a low-order digital filter model. A model with better physical interpretation could be easily developed.

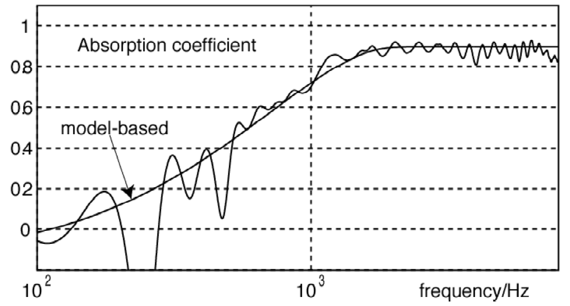

FIG. 3. Model-based curve fitting for smoothed absorption curve.

Model-based curve fitting is a useful method as far as there is evidence enough that the model used is physically valid for the case under study. On the other hand, it may easily yield inaccurate results that look reliable due to the smoothess of curves, and should therefore be used with caution.

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