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Uncertainty of array-based measurement of radiated and absorbed sound intensity

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ABSTRACT

Patch near-field acoustic holography (NAH) coupled with an array of sound intensity probes allows separating the sound field incident on a surface from the one radiated by the surface itself. Although the measurement principle has been successfully used to separate the noise source contribution from disturbing sources and/or noise reflections, the method accuracy has not been investigated in the literature. We describe the results of experiments meant to evaluate the uncertainty in the identification of noise radiated by vibrating panels with different absorption characteristics in presence of an incident acoustic radiation using the statistically optimized near-field acoustic holography. Measurement errors were evaluated through tests performed in controlled acoustic conditions. Results evidenced that the measurement uncertainty depends on the accuracy of the microphone array positioning and on the incident sound field. These conclusions were in agreement with the results obtained by simulations in the phase of instrument optimization.

1. Introduction

Despite the diffusion of measurement systems based on the near-field acoustic holography (NAH), the number of researches focused on their uncertainty is limited [1–5]. In general, the study of instrumental uncertainty in acoustics is not as diffused as for other kind of measurements [6], mainly because there are many factors (e.g. the measurand variability or the randomness of events that may occur during on-field measurements) whose contribution on data variability may be larger than the instrument uncertainty itself.

NAH [7] requires that the sound pressure tends to zero at the extremes of the measurement surface, in order to limit the truncation errors [8]. An accurate reconstruction of the sound field can be obtained with a large holographic plane that requires a large microphone array or multiple positioning of a small array in order to cover a large area with different measurements. Among the patch techniques, the statistically optimal near-field acoustical holography (SONAH) avoids the errors caused by the use of spatial Fourier transform by calculating the plane-to-plane reconstruction in the spatial domain instead of the spatial frequency domain [9]. SONAH can be used to measure the acoustic radiation of mechanical elements with an indirect measurement principle [10,11]. For current purposes, it is necessary to identify the different total intensity (I_{tot}) components at the vicinity of the panel: the radiated intensity (hereinafter I_{rad}), the incident intensity (I_{inc}) and the scattered intensity (I_{sc}). This can be performed using two parallel planar arrays of microphones (referred to as dual layer array, DLA). With measurements taken simultaneously in two parallel planes, it is possible to distinguish and resolve the incident (I_{inc}) and outgoing (I_{out}) sound field components with sources on opposite sides of the array. In order to separate the different components of the outgoing field (I_{out}), two measurement sessions are needed:

(1) Surface properties measurements (SPM), where the incident sound field created by a set of loudspeaker is used to estimate the surface admittance and absorption coefficient.
(2) Operational measurement (OM), where data derived in the SPM are used to separate I_{tot} in its three components I_{rad}, I_{inc} and I_{sc}.

In this paper, we describe the result of experiments performed to identify the uncertainty of measurements based on patch NAH using a microphone-array in a double layer configuration. The proposed approach for the evaluation of uncertainty can be summarized as follows:

1. Identification of the candidate factors that may affect the performances of the instrument starting from a literature analysis;
2. Experimental session in an anechoic room to identify the measurement repeatability and reproducibility;

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3. Comparison with the results obtained in the instrument design phase (described in Ref. [5]), in which an innovative method was used to predict the instrument uncertainty;

The paper is presented as follows: Section 2 describes the proposed method; experimental results are presented in Section 3 and discussed in Section 4. The paper conclusions are drawn in Section 5.

2. Method

SONAH measurement uncertainty has been estimated with experiments performed in controlled conditions, using design of experiments (DOE) to optimize the efforts for an exhaustive characterization.

2.1. Overview

Four series of experiments are performed in an anechoic room. In the simplest one, the DLA is used to measure the sound intensity emitted by a plate without disturbances, at a single array position. Even in this case, the error depends on where the calculation points are with respect to the array, on the array positioning method, on the source characteristics and on the adopted regularization algorithm. In the second series of experiments, each measurement is a combination of two array positions. The analysis of variance (ANOVA) is initially performed on the results of measurement of the surface properties, to identify the effect of the loudspeaker position, of the array positioning method and of the overlap between neighboring array positions. During the operational measurements, ANOVA is used to identify the effect of the emitting surface property, array positioning method and overlap on the radiated intensity. In the last series of experiments, the admittance-based and the energy-based approaches are compared with different incident noise levels.

The expected results derived from the analyses are the identification of the level of disturbances acceptable to obtain the desired measurement uncertainty and the comparison of experimental results with the ones of simulations performed in the design phase.

2.2. Experimental setup

Tests were performed in the anechoic room at Brüel & Kjaer SVM A/S in Naerum, Denmark. Vibration generated by a piezoelectric shaker (sine on random excitation with four tonal components at 500, 1000, 2000 and 4000 Hz) was imposed to two elastically suspended aluminum plates 500x600 mm in size. The first one was flat and 1 mm thick. The second one was 2 mm thick and 15° bent in the center. In both cases, the shaker was fixed with three screws (in central position on the flat plate, below the corner of the bent plate). The DLA was set-up with two 8x8 microphones arrays with a 30 mm spacing, (both between the two planes and between neighboring microphones in each plane). The DLA position was determined by an infrared positioning system (3D Creator WU-0695-W-001). Three omni-directional loudspeakers were used to create the incident field in both the operational and surface property measurement sessions. The experimental setup is shown in Fig. 1.

2.3. Experiments

Repeatability is defined by the ISO VIM [12] as the closeness of the agreement between the results of successive measurements of the same measurand, carried out under the same conditions. Reproducibility is the closeness of the agreement between the results of measurements of the same measurand carried out under changed conditions. The repeatability has been evaluated with experiments in which the only active source is the shaker; in these conditions, I_{rad} and I_{tot} are coincident. Tests were performed with two DLA positioning methods (hand held and tripod) on two plates. With the tripod positioning, the repeatability was evaluated with 8 identical measurements with a unique DLA position. The reproducibility was evaluated by removing and replacing the DLA in front of the vibrating plate in a nominally identical position. In hand-held measurements, the repeatability was evaluated with six repetitions carried out by a single operator in nominally identical conditions. The reproducibility was assessed starting from the results of tests carried out by three operators.

Admittance and absorption coefficient uncertainties (U_{adm} and U_{abs}) were evaluated with the A approach of the ISO-GUM [13] creating an incident sound field on the bent panel covered by two foam types with three omnidirectional loudspeakers. The sound sources (emitting incoherent white noise) were located at different heights at a distance of 2 m from the panel. SONAH was used to identify the sound pressure and the particle velocity on the panel surface, and thus to estimate the panel admittance and absorption coefficient. The results of each measurement session are the local admittance and absorption values: local data have been summarized with the mean (hereinafter referred to as average admittance μ_{adm} or absorption μ_{abs}) and with the standard deviation σ_{adm} and σ_{abs}. Given that the output of the SPM is the averaged absorption coefficient over pre-defined control areas, we have chosen to replace σ_{abs} with the difference between μ_{abs} measured on the two control areas (the upper and lower panel half). Two full 2^3 designs (investigation of 3 factors, each of them assuming 2 values [14]) were adopted with three repetitions for each test; totally, 24 tests were performed. Investigated factors were the DLA positioning method (tripod – hand held), the position of the loudspeakers during the surface properties measurement session (symmetrical and asymmetrical) and the array position overlap (with 1 or 3 overlapped microphone rows, as in Fig. 2). In the symmetrical configuration, the central loudspeaker were located in front of the shaker and the other two were placed 2 m apart. Conversely, in the asymmetrical configuration the central loudspeaker was moved 0.3 m apart from one of the two side sources.

The mapped areas with a "low" and with a "high" overlapping led to different mapping area sizes (882 cm^2 and 756 cm^2 respectively), since the adoption of a large overlap between two adjacent DLA positions leads to a smaller total area. Since the surface is homogeneous, the surface properties are reasonably constant on the whole surface; consequently, the computation of the averaged admittance (or absorption coefficient) on different areas leads to similar results. Results were analyzed using the ANOVA.

Uncertainty in operational measurements has been identified with two series of tests. In the first one, the investigated factors were the I_{inc} level and the SPM data used to estimate the admittance (included to investigate the effect of SPM repeatability on OM). Consequently, the SPM factor assumed three values, i.e. the three different experimental sessions in which the surface admittance has been measured. I_{inc} assumed two values: the low one was 5 dB smaller than I_{rad}, while the high level was 10 dB larger than I_{rad}. In the second series of tests, the investigated factors were the DLA positioning method (tripod – hand held), the array overlapping and the level of the incident sound field (white noise uncorrelated with the shaker stimulus). Both series of tests include 24 measurements (8 configurations of the 2^3 design, repeated three times each); in each of the 24 OM tests, I_{rad} can be computed using any result of the surface measurement session. Consequently over 1000 I_{rad} estimations can be theoretically computed (the combination of 24 operational tests, 24 surface tests and the use of admission and absorption coefficient). In order to ease the results analysis, I_{rad} was computed using a single estimation of the surface