Loudspeaker cabinet characterization using a particle-velocity based scanning method

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Introduction

Loudspeaker cabinet design pursues to provide the appropriate acoustic loading for the drive units while ensuring a good performance of the complete system [1]. The vibrations induced by the driver frame and moving airmass within the enclosure should be therefore controlled in order to minimize the radiation from the cabinet itself. There are several methods to capture and visualize the vibro-acoustic behaviour of a radiating sound source, but often they are tedious or impractical.

Nearfield acoustic holography (NAH), for instance, uses an inverse approach to predict the surface displacement of a vibrating object based upon acoustic measurements, traditionally performed with pressure microphones. However, the complex analytical models required to back-propagate the acquired data are fairly sensible to the acoustic environment and complex source nature. Thus, NAH is not suitable for every measurement case.

In contrast, direct sound field visualization offers a more flexible approach to display sound phenomena. Sound maps are excellent tools for building understanding about a wide range of specific problems. Novel scanning methods have been recently introduced to accurately map stationary sound fields in an efficient way. In the previous literature, sound pressure, particle velocity, intensity, sound absorption and acoustic impedance have been measured with a new scanning method developed by Microflown Technologies called "Scan & Paint" [2]. This methodology is based upon the acquisition of acoustic data by manually moving a P-U probe (pressure-particle velocity sensors) across a sound field whilst filming the event with a camera. It is then possible to visualize sound variations across the space in terms of any acoustic quantity. This efficient measurement method allows us to display the sound field and also assess the dynamic behaviour of the enclosure via particle velocity. In addition, the pressure contribution from the different cabinet sides can be calculated by applying transfer path analysis to the acquired data.

The measurement methods presented in this paper provide novel approaches for enhancing a cabinet design in a fast and efficient way. The main advantages of the proposed procedure are linked to the use of a single scanning probe. Results from direct sound visualization, intensity vector field investigation, operational deflections shapes and panel noise contribution analysis are presented throughout the following sections.

Scan & Paint

The scanning sound visualization technique used to acquire the data presented in this paper is called "Scan & Paint" [2]. The acoustic signals of the sound field are acquired by manually moving a single transducer across a measurement plane whilst filming the event with a camera. In the post-processing stage, the sensor position is extracted by applying automatic colour detection to each frame of the video. It is then possible to split the long recording into multiple segments by applying a spatial grid algorithm [3]. Each fragment of the signal will be linked to a grid cell, depending upon the position of the probe during the measurement. Spectral variations across the space are computed by analysing the signal segments of each grid section.

An example of the loudspeaker front radiation is presented in Figure 1. A measurement sweep of about three minutes was performed to acquire the data displayed. As is shown, particle velocity maps allow us to unequivocally identify the location of the excitation points along the cabinet, regardless of the frequency range evaluated.

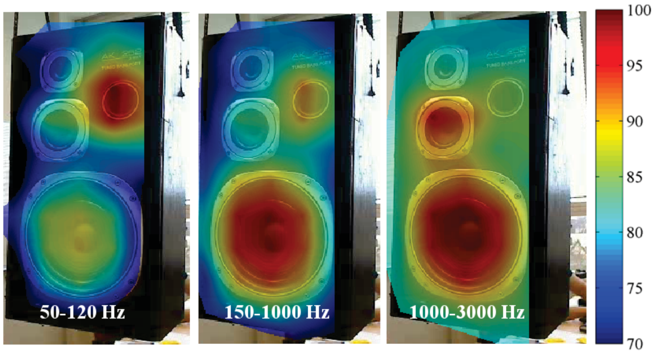

Figure 1: Particle velocity maps of the front side of the cabinet.

Scanning Operational Deflection Shapes

Understanding the dynamic behaviour of a component, machine or structure is a key factor for controlling noise, vibration, fatigue or wear problems. Conventionally, analytical modal analysis is used to characterize resonant vibration in machinery and structures from a theoretical point of view. However, it is often required to study a structure under a number of different operating conditions. For particular scenarios it has been proven that direct measurements are faster, simpler and more accurate than analytical predictions [4]. Experimental modal analysis can be performed by measuring Operational Deflection Shapes (ODSs), and then interpreting or post processing them in a specific manner to define mode shapes [5, 6].

To understand the physical meaning of an ODS, they could be seen as the picture which would be obtained if a stroboscope were used to freeze a vibrating object at a desired frequency. Hence, an ODS is an observation, or visualization, of particular dynamic behaviour but it does not give the characteristic dynamic properties of a particular structure.

Several studies have revealed the potential of using P-U probes for measuring structural vibrations with step-by-step techniques and recently, also with scanning methods [7]. Scanning measurement techniques allow to reduce the number of sensors, time and cost of the experiments but constrained to assess time-stationary sound fields. In our case, the source is driven with the desired excitation and hence is not a problem to meet the time-stationary requirement.

Performing scanning measurements of particle velocity in the vicinity of the vibrating surface lead us to investigate the ODS of the structure. The average narrow band spectrum has been calculated in order to localize the critical frequencies of the cabinet, where the displacement is maximum. Next, it has been produced a colourmap evaluating a 10 Hz band centred at the main resonance frequencies. As can be seen in Figure 2, each particle velocity map illustrates a clear cabinet ODS. These intuitive maps could be used to improve the current loudspeaker cabinet design by applying a special treatment to the areas of maximum displacement.

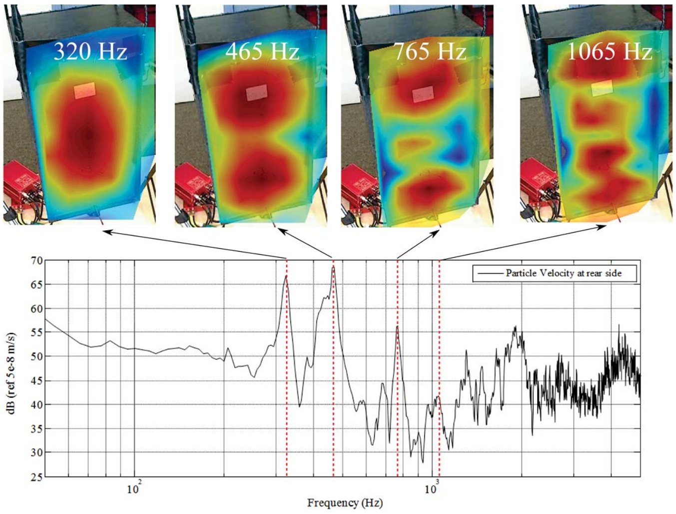

Figure 2: Particle velocity maps of the rear side of the cabinet (top) and average particle velocity spectrum (bottom).

Intensity vector field mapping

Visualization of sound intensity may involve depicting various acoustic phenomena, depending on the area of interest. In sound engineering, it may be an acoustic wave power density distribution in space, the wave dissipations, the evaluation of its motion within the medium, spatial diffusion and frequency irregularities of sound velocity. For technical acoustics, directional characteristics of industrial sources and the variables connected with reflection, scattering and diffractions on obstacles, could prove interesting.

The scanning methodology previously introduced can also be used with a three dimensional sound probe which incorporates three orthogonal particle velocity sensors along with a pressure microphone. The three dimensional acoustic intensity is then computed by calculating the real part of the cross-spectra between pressure and particle velocity components. As a result, direct measurements of the intensity vector field of the evaluated scenario can be performed if the orientation of the probe is maintained during the acquisition process.

First of all, the front radiation from a loudspeaker was investigated in a conventional room at 1 kHz, in order to display the acoustic energy flow in the proximity of the speaker. Figure 3 presents the experimental result obtained.

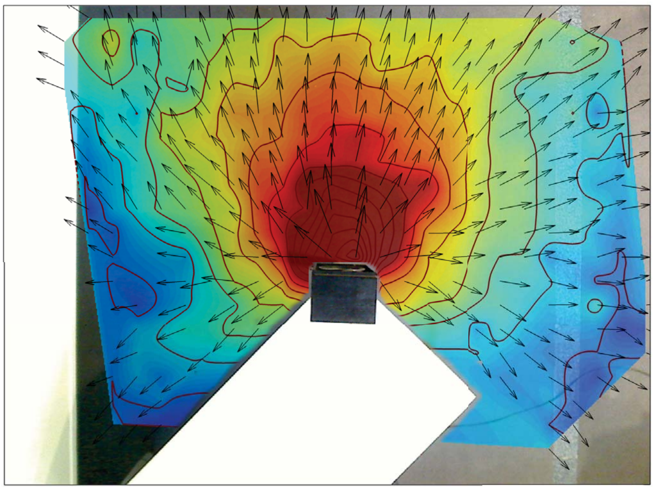

Figure 3: Experimental sound intensity vector field generated by a loudspeaker with a 1 kHz sinusoidal excitation (top view).

It is worth highlighting the diffraction effect introduced by the cabinet shape. When the wavefronts generated at the speaker driver reach the sharp edge of the cabinet there is a sudden increase in the rate of expansion [8]. There are two consequences of this effect. First, part of the acoustic energy radiated effectively turns around the edge and carries on propagating into the region behind the plane of the source. Second, a new sound wave appears to be emanated from the edge, the so called diffracted wave. This effect causes that the particle velocity measured in the sides of the loudspeaker is a combination of structure-borne sound radiated by the cabinet and the airborne sound coming from the driver. Consequently, additional structural transfer function measurements would be required in order to separate structure-borne and airborne noise.

In addition, a loudspeaker high-frequency radiation map is presented in Figure 4. At 5 kHz, the wavelength becomes small compared to the cabinet size, producing a directivity pattern which could be approximated by a rigid piston in an infinite baffle. From the figure is also clear that most of the energy propagates away from the cabinet; moreover, the diffraction effect at high frequencies is less significant.

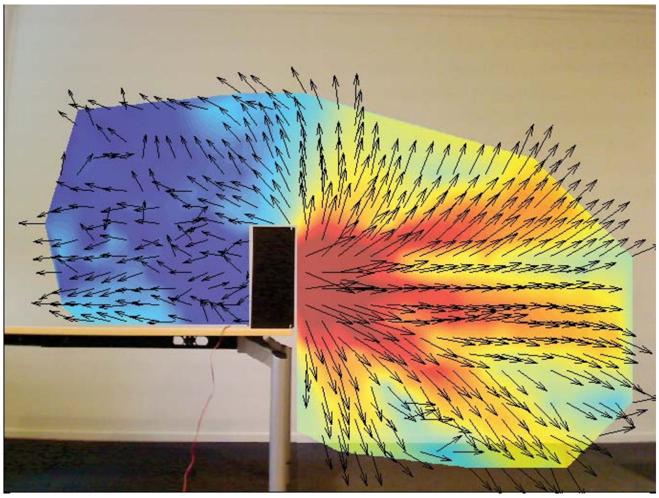

Figure 4: Experimental sound intensity vector field generated by a loudspeaker with a 5 kHz sinusoidal excitation (side view).

Scanning Transfer Path Analysis

Direct sound field visualization is not always the best way to assess complex noise problems. Maps of sound pressure, particle velocity or sound intensity in the vicinity of a cavity panel are not enough to evaluate the pressure contribution at a certain position. Transfer Path Analysis (TPA) has been implemented for many years to evaluate this case scenario. The complex radiating structure is usually discretized into multiple vibrating surface areas denoted as 'panels' . Then, their degree of "contribution" should be defined in order to rank which panels has a stronger influence on causing the sound pressure at the evaluated position. This problem is normally referred as "Panel Contribution Analysis". In the technical literature, several experimental techniques can be found that assess this problem. Most commonly used methods within Airborne TPA are"windowing" techniques [9], substitution monopole techniques (SMT) [10, 11], matrix inversion methods [12], direct particle velocity measurements [13, 14, 15], beamforming [16, 17] and holographic technologies using pressure arrays [18, 19].

The most common measurement procedures require the use of large microphone arrays, meaning high cost, time and frequency limitations. The measurement method Scan & Paint can be also adapted for applying TPA techniques providing the sound field is stationary [20]. A two steps measurement approach is implemented: first the sound field is scanned under operational conditions and then the process is repeated, exciting with a monopole source at a reference spot. Figure 5 shows the measurement setup used during the experiments.

The six sides of the loudspeaker cabinet where measured using scanning measurements in both operational conditions and exciting with a monopole source. It is then possible to reconstruct the sound pressure at the reference position by integrating the product of all excitation sources and their corresponding propagation paths. Figure 6 presents a direct comparison between the measured and synthesized pressure. As it can be seen, the two results are in good agreement, which indicates the validity of the measurement procedure.

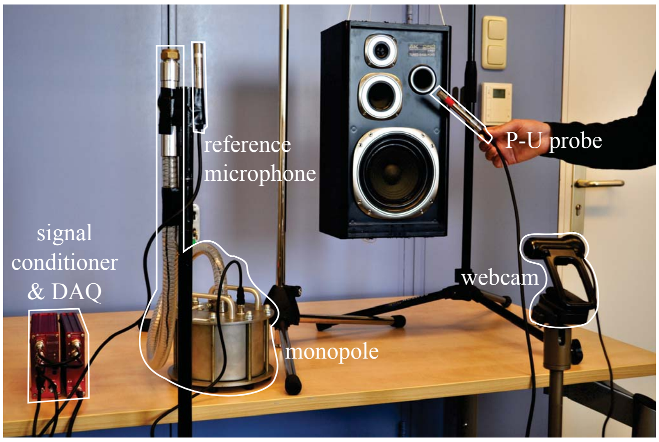

Figure 5: Experimental setup of the scanning transfer path measurements.

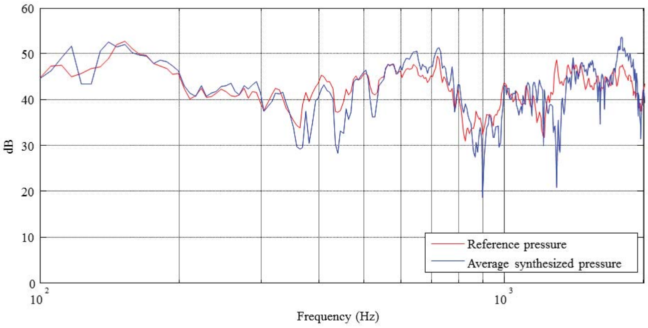

Figure 6: Measured (red) and reconstructed (blue) reference pressure using scanning transfer path analysis techniques.

As it has been shown in Figure 2, the rear side of the cabinet presents several strong resonances that might be affecting the pressure received at the reference position. Thus, it is important to compute the pressure contribution of this side to evaluate its impact in the received reference pressure. Figure 7 presents the results found after applying scanning transfer path analysis [20].

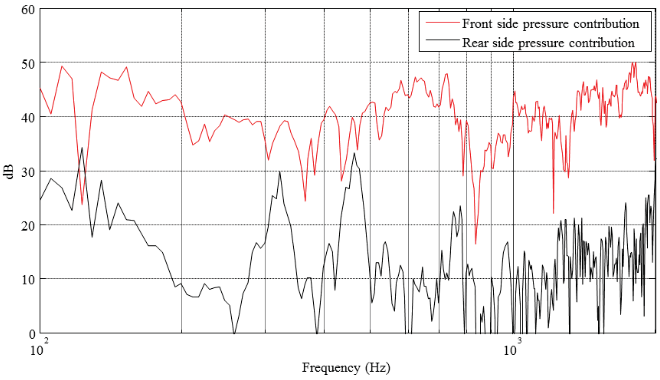

Figure 7: Pressure contribution of rear (black) and front (red) sides of the cabinet.

The result presented above shows that the rear side of the cabinet can become problematic at the resonance frequencies of the enclosure, in this case, most significantly at 465 Hz. The undertaken assessment is therefore suitable for detecting structural weaknesses which can bias the final loudspeaker performance.

Conclusions

The sound field generated by a loudspeaker has been investigated using scanning intensity techniques. The use of a three dimensional sound probe has revealed radiation patterns and diffraction phenomena of the evaluated loudspeaker system. The vibro-acoustic behaviour of the enclosure has been characterized via visualization of operational deflection shapes and particle velocity spectra, finding the critical areas which should be treated in order to improve the loudspeaker performance.The application of scanning transfer path analysis have ultimately shown the impact in the pressure contribution of potential problematic structure-borne sound radiated by the cabinet structure.

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