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Source fields reconstruction with 3D mapping by means of the virtual acoustic volume concept

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ABSTRACT

This paper presents the theoretical framework of the virtual acoustic volume concept and two related inverse Patch Transfer Functions (iPTF) identification methods (called u-iPTF and m-iPTF depending on the chosen boundary conditions for the virtual volume). They are based on the application of Green's identity on an arbitrary closed virtual volume defined around the source. The reconstruction of sound source fields combines discrete acoustic measurements performed at accessible positions around the source with the modal behavior of the chosen virtual acoustic volume. The mode shapes of the virtual volume can be computed by a Finite Element solver to handle the geometrical complexity of the source. As a result, it is possible to identify all the acoustic source fields at the real surface of an irregularly shaped structure and irrespective of its acoustic environment. The m-iPTF method is introduced for the first time in this paper. Conversely to the already published u-iPTF method, the m-iPTF method needs only acoustic pressure and avoids particle velocity measurements. This paper is focused on its validation, both with numerical computations and by experiments on a baffled oil pan.

1. Introduction

The localization, quantification and ranking of noise sources is a challenging task for sound and vibrations engineers. These last years, the tightening of noise emission standards has increased the need for efficient noise source identification methods to figure out where design changes are necessary to improve the overall noise radiation. This implies to identify fields or information directly on the real geometry of complex structures, in order to provide a better understanding of noise sources and to make possible sub-systems ranking. Moreover, in this industrial context, other constraints like the source's environment, potentially noisy or cluttered, have to be addressed at the same time.

Among all techniques existing in the field of source identification [1,2], the methods based on Nearfield Acoustical Holography (NAH) appear to be the most appropriate to achieve these objectives. They rely on the back propagation (contactless) of the sound field measured near the source to reconstruct both in terms of localization and quantification all source fields (pressure, velocity and intensity). Since several decades, many identification methods based on NAH have been developed or combined to overcome their respective limitations [3] or to deal with more challenging and specific applications like transient cases [4]. Considering stationary sources, these methods generally differ from the coordinate system used to decompose the sound field. To cite the most well-knowns, the 2D FFT-NAH [5,6] was derived in planar, cylindrical

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and spherical coordinate systems, the SONAH (Statistically Optimized NAH) algorithm relies on planar waves expansion [7] and the HELS (Helmholtz Least Square Method) based methods on cylindrical or spherical waves functions [8,9]. As a consequence, each of these methods is dedicated to a well specific microphone array (planar, cylindrical or spherical), making possible the reconstruction only on this kind of geometry. A possibility to get a quite conformal mapping of the sound to an arbitrary shaped source, is to combine several maps scanned around the source with a reduced planar microphone array and the SONAH algorithm [10]. This approach requires that the source is easily accessible and it seems to be more practical with a hand-held array. Another solution dedicated to an arbitrary shaped structure is to build numerically the transfer matrix by using the BEM formulation [11–13]. However, in that case, the propagation of sound waves from the source should be in free field conditions. A noisy environment can be addressed by an appropriate source separation technique (double information measurements on one layer with collocated pressure and particle velocity measurements [14,15], or on double layers (pressure [16,17] and/or velocity [18,19])), but these classical identification methods are not suitable for cluttered sources.

A solution to deal with the constraint of the source's environment is to consider it, both physically (presence of obstacles for example) and acoustically (presence of disturbing sources for instance) in the problem formulation. This is the general idea of the virtual acoustic volume concept and related identification methods [20]. Their basic principle relies on an inverse problem, formulated from the definition of an arbitrary closed virtual volume surrounding the source with the application of Green's identity. This arbitrary volume can be chosen as convenient, i.e. to follow the source geometry is not compulsory and the use of Green's identity allows being independent of the acoustic environment as a separation technique. The reconstruction of sound source fields combines acoustic measurements performed at discrete accessible positions in this virtual volume to its modal behavior which is used as a basis of solution expansion. The mode shapes can be computed numerically by means of a Finite Element solver, making possible the processing of irregular virtual volume and source geometries. As a result, all the acoustic source fields (velocity, pressure and intensity) can be identified directly on the source geometry (3D mapping) and from a measurement process that can be adapted to the source environment. Due to its formulation, Green's identity offers the possibility to choose the virtual boundary conditions of the virtual volume, resulting in many possible fully fledged identification methods. In this paper, these methods are denoted as inverse Patch Transfer Functions (iPTF) methods and distinguished according to the virtual boundary conditions used. Two interesting configurations are explained in this paper. The first one corresponds to the already published iPTF method, denoted as u-iPTF as it relies on a uniformly rigid virtual volume [20–22]. It requires collocated pressure and particle velocity measurements to reconstruct all the acoustic fields on the real geometry of the source [23–25]. This can be done using a pU probe but its cost still remains currently a limitation for an industrial utilization. To overcome this drawback, a new method denoted as m-iPTF is introduced in this work. It needs only pressure measurements as it relies on mixed virtual boundary conditions to avoid the expensive particle velocity measurements.

2. Inverse methods based on the virtual acoustic volume concept

2.1. Theoretical framework

Let us consider a general vibro-acoustic problem presented in Fig. 1 where an irregularly shaped vibrating structure of surface Σ radiates in any environment. It may be noisy (presence of stationary disturbing sources), reverberant (presence of rigid walls denoted Σ''), geometrically complex (presence of objects) or unknown (surface impedances not defined or unknown).

The aim is to reconstruct the source fields on the surface Σ by measuring radiated acoustic quantities at accessible positions around it. For this, let us define a virtual surface Σ' surrounding the source, which is theoretically used to separate

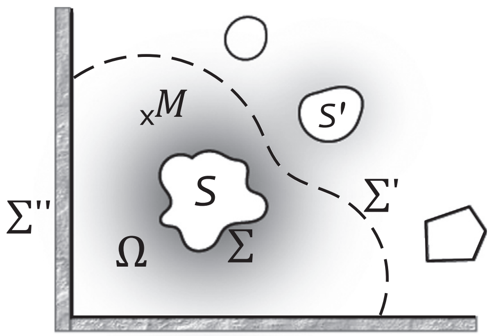

Fig. 1. Definition of the closed virtual volume Ω and its boundary surfaces: Σ (surface of the vibrating source), Σ' (virtual surface surrounding the source) and Σ'' (physically rigid wall).