Noise and Vibration: *Emerging Methods*
NOVEM 2009
5-8 April 2009 Oxford

IDENTIFICATION OF SOURCE VELOCITIES IN PRESENCE OF EXTERNAL CORRELATED SOURCES WITH THE INVERSE PATCH TRANSFER FUNCTIONS (IPTF) METHOD

M. Aucejo[1] , N. Totaro[1] and J.-L. Guyader[1]

[1]Laboratoire Vibrations Acoustique de l'INSA de Lyon,
25 bis, avenue Jean Capelle, 69621 VILLEURBANNE Cedex, FRANCE
Email: mathieu.aucejo@insa-lyon.fr
Email: nicolas.totaro@insa-lyon.fr
Email: jean-louis.guyader@insa-lyon.fr

ABSTRACT

The identification of source velocities has been developed through several methods such as Nearfield Acoustical Holography (NAH) or inverse Boundary Element Method (iBEM). However, these methods fail to identify source velocities in presence of disturbing sources and need free field conditions. The inverse Patch Transfer Functions (iPTF) method proposes to overcome this difficulty through the double measurement of pressure and particle velocity fields on the open surfaces of a virtual cavity arbitrarily defined around the source. In the method, measurement and identification surfaces are divided into elementary areas called patches. Source velocities are then obtained from the acoustic field and the Patch Transfer Functions computed by Finite Element Method. The iPTF method can also be applied on complex 3D geometries and measurements can be performed in situ. In the present paper, the basic equations of the method are reminded and an experimental validation on simple source geometry (two baffled pistons) is presented and discussed.

1 INTRODUCTION

Nearfield Acoustical Holography (NAH) and inverse Boundary Method (iBEM) are holographic methods developed to identify acoustic field on a structure when direct measurements are unavailable.

The NAH firsly introduced by Williams et al. [1] is based on the spatial Fourier Transform of the pressure field measured on a hologram near the source at a given frequency. This method allows determining the three-dimensional source velocity field. However, NAH remains mainly applicable to simple geometries.

The iBEM belongs to inverse Frequency Response Function methods (iFRF), which are based on experimental or numerical evaluation and inversion of transfer matrices. In iBEM, the BEM is used to compute the transfer matrices. Although iBEM can be applied on complex structures, the inversion of transfer matrices remains a delicate issue because of their ill-conditioning. Similarly, iBEM needs a fine mesh definition (6 nodes per wavelength) to identify acoustic field, wich can lead to an excessive amount of measurements.

Neverthless, hybrid methods like hybrid NAH [2] were developed to overcome the inherent limitations of NAH and iBEM. But like previous methods, it requires a regularization of matrices to limit the effects of measuring uncertainty and incompleteness of acoustic pressure field.

In this paper, the inverse Patch Transfer Functions method (iPTF) is introduced to identify source velocities. This formulation is derived from the PTF method [3], which is a prediction tool of acoustic pressure inside and outside a cavity containing sources and apertures based on substructuring and acoustic impedance concepts. In this method, the acoustical medium is indeed divided into subdomains, which coupling surfaces are divided into elementary areas called patches. The iPTF method proposes to identify source velocities on complex structure thanks to the double measurement of patch pressure and patch particle velocity on a virtual acoustic cavity surrounding the source. By this way, this method is applicable to non anechoic environments and in presence of a disturbing source, which allows performing measurements *in situ*.

2 THEORETICAL BACKGROUND OF THE IPTF METHOD

The iPTF method is based on the definition of an arbitrary virtual acoustic cavity surrounding the source to identify (see Figure 1). The acoustic problem is governed by the Helmholtz equation in the virtual cavity Ω_i. On boundaries, a normal harmonic particle velocity $\bar{V}_n e^{j\omega t}$ is imposed on the source surface S_v, while the normal harmonic particle velocity $\bar{V}_n^{rad} e^{j\omega t}$ on S_m results from the radiation of the source in the acoustic medium. Consequently, the virtual cavity problem to solve is given by Equation 1.

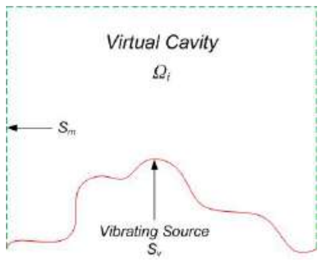


Figure 1. Definition of the virtual acoustic cavity surrounding the source

$$\begin{cases} \Delta p\,(M) + k^2 p\,(M) = 0 & \forall\, M \in \Omega_i \\ \dfrac{\partial p}{\partial n}\,(M) = -j\rho\omega \bar{V}_n(M) & \forall\, M \in S_v \\ \dfrac{\partial p}{\partial n}\,(M) = -j\rho\omega \bar{V}_n^{\,rad}(M) & \forall\, M \in S_m \end{cases} \tag{1}$$

Where Δ is the Laplacian operator, $\frac{\partial}{\partial n}$ the normal derivative, ω the angular frequency and *k* the acoustic wavenumber.

Patch Transfer Functions of the virtual cavity are firstly computed. For this purpose, the virtual cavity surface S is then divided into elementary areas S_p and the problem to solve for each patch is given by Equation 2.

$$\begin{cases} \Delta p\,(M) + k^2 p\,(M) = 0 & \forall\, M \in \Omega_i \\ \dfrac{\partial p}{\partial n}\,(M) = -j\rho\omega \bar{V}_{ni} & \forall\, S_p \\ \dfrac{\partial p}{\partial n}\,(M) = 0 & \forall\, M \in S \setminus S_p \end{cases} \tag{2}$$

The mean pressure $\langle p_j \rangle$, respecting Equation 2, is defined as the superposition of mean pressures due to normal velocities on patches of the virtual cavity surfaces S_v and S_m (see Equation 3).

$$\langle p_j \rangle = \sum_{k=1}^{P} Z_{jk} \langle v_k \rangle \; + \; \sum_{i=1}^{N} Z_{ji} \langle v_i \rangle \tag{3}$$

For a sake of simplicity, Equation 3 is rewritten under matrix form (see Equation 4).

$$\{P_j\} = [Z_{jk}]\{V_k\} + [Z_{ji}]\{V_i\} \tag{4}$$

In this equation, $\{V_k\}$ is the patch source velocity on surface S_v and $\{V_i\}$ is the patch radiated velocity by the source on S_m, while $[Z_{jk}]$ (resp. $[Z_{ji}]$) represents the patch impedance matrix between an excited patch *k* (resp. *i*) and a receiving patch *j*. These patch impedance matrices are obtained from the modal expansion of the virtual rigid wall cavity as expressed in Equation 5.

$$Z_{jk} = \frac{\langle p_j \rangle}{\langle v_k \rangle} = -\sum_n \frac{j\omega\rho c^2 S_k}{\Lambda_n(\omega_n^2 - \omega^2 + j\eta_n\omega_n\omega)} \langle \phi_n \rangle_k \langle \phi_n \rangle_j \tag{5}$$

Where ω_n and ϕ_n are respectively the natural frequencies and the modal shapes of the virtual rigid wall cavity. One has to notice that this modal basis can be obtained either analytically if the geometry of the cavity is simple or using numerical methods like FEM otherwise.

The aim of the iPTF method is to identify source velocities $\{V_k\}$. For that purpose, one uses Equation 4, which after simple matrix manipulation allows computing source velocities as expressed in Equation 6.

$$\{V_k\} = [Z_{jk}]^{-1}(\{P_j\} - [Z_{ji}]\{V_i\}) \tag{6}$$

Equation 6 shows that only patch pressure P_j and patch velocity V_i on surface S_m are required in the formulation to determine source velocities. These two last quantities are actually measured with a PU probe. Moreover, thanks to this integral formulation the method can be used in a non anechoic environment and in presence of sources located outside the virtual cavity. Like other source identification methods, the inversion of patch impedance matrices remains indeed a delicate issue because of ill-conditioning. However, a criterion has to be followed to avoid ill-conditioning. Indeed, the number of virtual cavity modes must at least be equal to the number of patches in order to describe properly the modal shapes and avoid under-determination of the problem.

3 EXPERIMENTAL VALIDATION OF THE IPTF METHOD

3.1 Experimental set-up

The experimental set-up consists of two baffled pistons exited in phase opposition. The rigid baffle is a wooden thick plate of dimension $700 \times 600 \times 40$ mm, in which two loudspeaker are inseted as presented in Figure 2. Furthermore, the identification area of dimension 450×350 mm is divided into 30 patches and the reference measurement is performed by measuring the particle velocity at the center of each patch in the very nearfield of the source. One can also notice that PU measurements is performed in a non anechoic room, which means that reflected sound from room boundaries influences PU probe measurement.

Finally, a parallelepiped virtual cavity of dimensions $450 \times 350 \times 20$ mm is defined around the source and divided into 139 patches, where pressure and particle velocity are measured at the center of each patch.

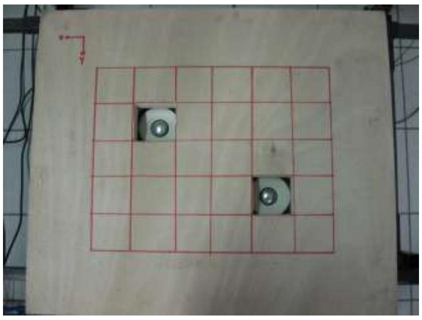


Figure 2. Definition of the experimental set-up

3.2 Validation of the method principle

To validate experimentally the principle of the method, Equation 6 is applied on the configuration defined in section 3.1. The application of the iPTF method from experimental data shows a agreement in both magnitude and distribution as presented in Figures 3 and 4.

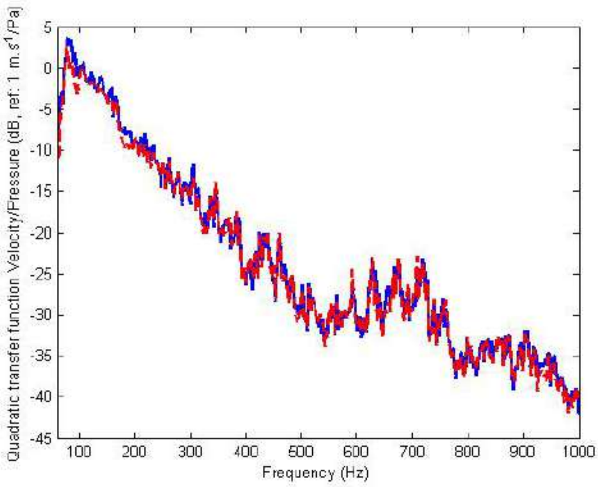
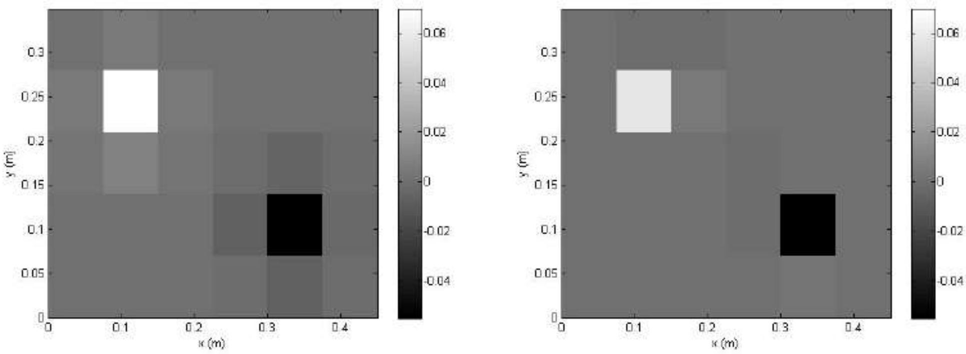


Figure 3: Comparison of quadratic transfer function Velocity/Pressure on the first excited patch for a $450 \times 350 \times 20$ mm virtual cavity, (-) Reference, (- -) Identification

3.3 Robustness of the method

As exposed in section 2, the iPTF method is theoretically independent of the presence a stationary disturbing source outside the virtual cavity. To prove this theoretical fact, a third correlated louspeaker is added (see Figure 5). This loudspeaker modifies the acoustic field in the measurement area, including the source surface. Consequently, the reference measurement is performed again to take into account the presence of the disturbing loudspeaker. As presented in Figure 6, the influence of the third loudspeaker is non negligible since the difference between pressure power spectrum measured with or without the disturbing source reaches 5 dB at certain frequencies.

In this example too, the iTPF method allows proper identifications in magnitude and spatial distribution since in Figure 7 identification differs from the reference by 3 dB at most on the considered frequency range. The comparison between reference map and the identified one in Figure 8 gives very satisfying results. That proves the efficiency of the method in presence of correlated disturbing source, which is an importante issue to identify source velocities *in situ*.



(a) (b)

Figure 4: Comparison between (a) the reference map measured at 5 mm from the source and (b) the identification map obtained experimentally with the iPTF method at 240 Hz for a $450 \times 350 \times 20$ mm virtual cavity

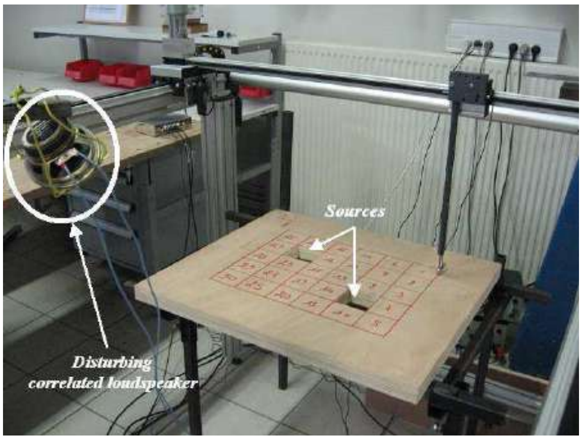


Figure 5. Location of the disturbing loudspeaker towards the measurement area

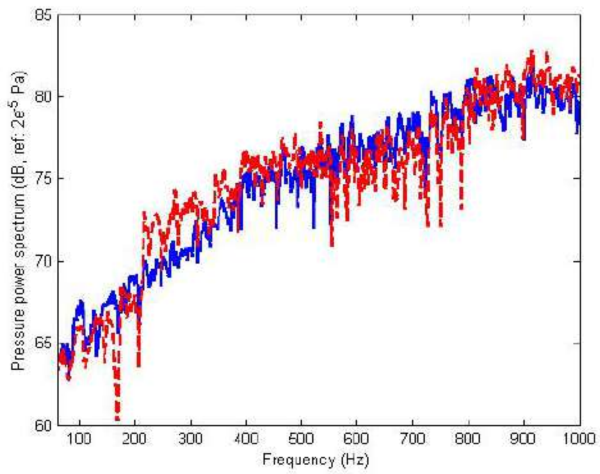


Figure 6: Comparison between the pressure power spectrum obtained on a patch of the measurement surface (-) without and (- -) with the disturbing source versus frequency

4 CONCLUSION

The iPTF method allows identifying source velocity field. Through a simple experimental validation, the ability of the method to identify and reconstruct the source velocity field with or without

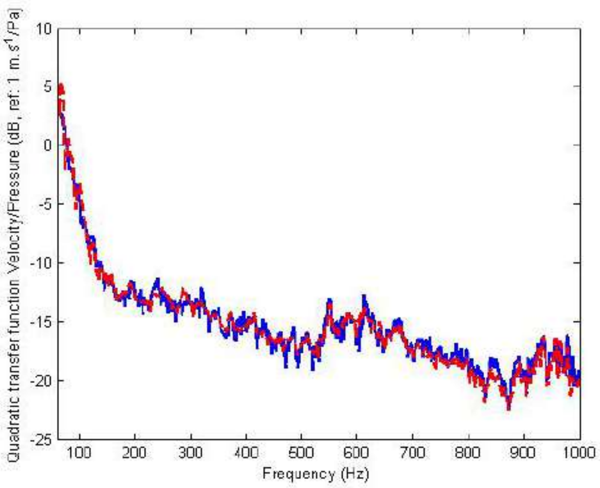


Figure 7: Comparison of quadratic transfer function Velocity/Pressure on the first excited patch in presence of a correlated disturbing source, (-) Reference, (- -) Identification

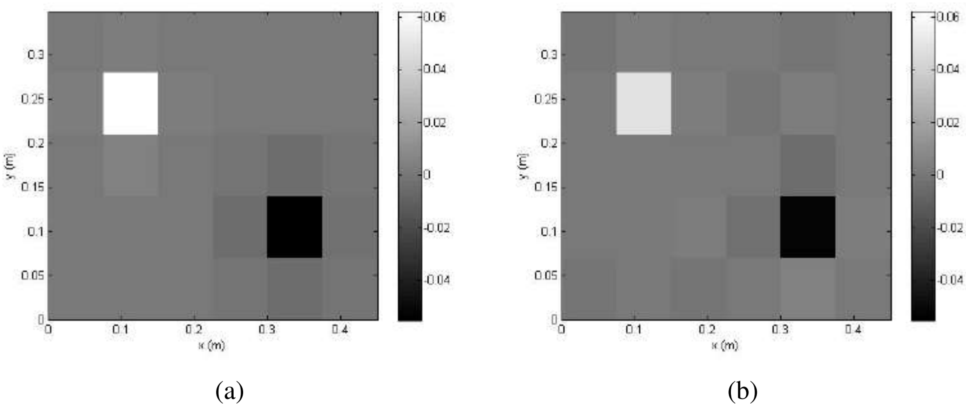


Figure 8: Comparison between (a) the reference map and (b) the identification map obtained experimentally in presence of a disturbing source with the iPTF method at 240 Hz for a $450 \times 350 \times 20$ mm virtual cavity

the presence of a stationary correlated disturbing source have been underlined. The main advantage of the method is the combined use of the integral formulation, FEM and PU measurements, which allows overcoming inherent limitations of classical methods. By this way, the method is independent of the environment, provided it is stationary, and can be applied on complex source geometry.

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