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FIELD RECONSTRUCTION IN CASE OF PARTIALLY MASKED ACOUSTIC SOURCES

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ABSTRACT

The inverse Patch Transfer Function (iPTF) method developed at the Laboratory of Vibration and Acoustics of INSA Lyon (France) allows reconstructing the acoustic pressure, velocity and intensity fields directly on the surface of an object of complex three-dimensional shape. Based on the concept of virtual volume modeled by finite elements, this method makes it possible to theoretically overcome stationary disturbing sources external to the volume. Finally, the method permits, thanks to a post-processing of the identified fields, to rank the contributions of parts to the radiated acoustic power and to compare with objective metrics (Response Vector Assurance Criterion) experimental measurements to numerical models. As such, this method opens the way to a complete characterization of sources in an industrial context. However, an industrial environment is often very far from a controlled laboratory environment. In particular, the source to be characterized may be maintained by rigid frames which make access to a microphone antenna difficult and it may also be masked by other parts that one does not wish to characterize. This paper shows how the iPTF method can be used when the source is partially masked by an object. The approach is illustrated by numerical experiments and an industrial application.

Keywords: *inverse Patch Transfer Function method, field reconstruction, masked object, virtual volume concept*

1. INTRODUCTION

Nowadays, characterization of acoustic sources is often done using field reconstruction techniques like nearfield acoustic holography and its variants [1][2][3]. These methods often reconstruct the acoustic fields on a simple surface (plane, sphere) close to the source of noise to be characterized. These methods are quite easy to use but there are often limited when dealing with a vibrating source with complex shape placed in a real industrial environment. A real industrial environment might consist in a source in a non-anechoic environment, with presence of disturbing sources, with presence of frames, wires, tubes that often mask the source to be characterized and make the use of NAH antenna tedious.

The inverse Patch Transfer Functions method (iPTF) aims at overcoming these difficulties by introducing the concept of a virtual acoustic volume (VAV) with specific, non-real, boundary conditions (this is why the acoustic volume is said to be virtual) [4][5]. The iPTF method has already been applied successfully in an industrial environment but dealing with the presence of obstacle was not previously considered. The present paper explains how a rigid masking object can very easily be introduced in the iPTF formulation. A numerical as well as an industrial application are presented.

2. HANDLING MASKING OBJECTS IN IPTF FORMULATION

The iPTF formulation, detailed in [4] and [5], relies on the definition of a virtual surface enclosing the vibrating source under study as presented in Figure 1(a). The vibrating source surface Σ_s and the virtual surface Σ_v define a virtual acoustic volume (VAV). Using the Green's identity, it is possible to express the acoustic pressure at point Q as a function of pressure and normal particle velocity on surfaces Σ_s and Σ_v and as a function of virtual mode shapes $\phi_n(Q)$ as expressed in Eqns. (1) and (2).

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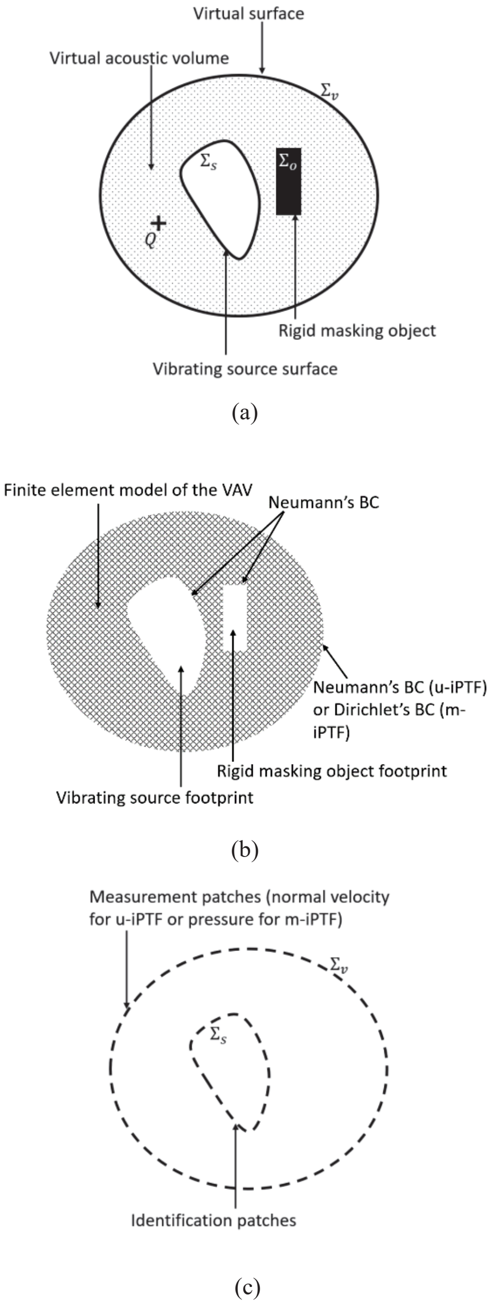


Figure 1. iPTF approach in the presence of a masking object. (a) Virtual surface and virtual acoustic volume; (b) finite element model of the virtual acoustic volume and the corresponding boundary conditions; (c) measurement and identification patch meshes

$$p(Q) = \sum_{n=1}^{\infty} \frac{\phi_n(Q)}{(k^{*2} - k_n^2)\Lambda_n} C_n \tag{1}$$

$$C_n = \int_{\Sigma} p(Q)\frac{\partial \phi_n(Q)}{\partial n} - \phi_n(Q)\frac{\partial p(Q)}{\partial n} \mathrm{d}\Sigma \tag{2}$$

where k^* and k_n are respectively the complex acoustic wavenumber ($k^* = k(1 + \mathrm{i}\eta)^{-1}$, η being the damping factor of air) and the acoustic wavenumber of mode n of the virtual mode shape $\phi_n(Q)$.

The iPTF approach comes in two different versions depending on the boundary conditions set for the virtual acoustic volume. As can be seen in Figure 1(a), for the u-iPTF (iPTF with uniform boundary conditions) Neumann's boundary conditions are considered for both surfaces Σ_s and Σ_v whereas for the m-iPTF (iPTF with mixed boundary conditions) a Neumann's boundary conditions is considered for Σ_s and a Dirichlet's boundary condition is set for Σ_v.

Considering the real continuity Euler's relation between pressure and particle velocities on surfaces and discretizing the integral on elementary surfaces called patches, on can derive Eqn. (3) for u-iPTF and Eqn. (4) for m-iPTF.

$$\mathbf{V}_j = \mathbf{Z}_{ij}^{-1}(\mathbf{p}_i - \mathbf{Z}_{ik}\mathbf{V}_k) \tag{3}$$

$$\mathbf{V}_j = \mathbf{Z}_{ij}^{-1}(\mathbf{p}_i + \mathbf{Y}_{ik}\mathbf{p}_k) \tag{4}$$

where $\mathbf{V}_j$ is the vector of normal particle velocities for the n_s patches discretizing the vibrating source surface: this vector is the unknown of the problem. $\mathbf{p}_k$ and $\mathbf{V}_k$ are respectively the pressure and the normal particle velocity on the n_v patches discretizing the measurement surface: these quantities are measured. $\mathbf{p}_i$ is the vector of pressure measured at n points inside the virtual volume. Finally, $\mathbf{Z}_{ij}$, $\mathbf{Z}_{ik}$ and $\mathbf{Y}_{ik}$ are transfer matrices between patches of the vibrating surfaces and the n points inside the volume (matrix of dimension $n_s \times n$) or between patches of the vibrating surface and patches of the measurement surface (matrix of dimension $n_s \times n_v$).

The mode shapes of the virtual acoustic volume are extracted numerically using a FE solver.

For the u-iPTF, acoustic pressure as well as particle velocity have to be measured on the virtual surface and only pressure mode shapes are needed. On the other hand, for the m-iPTF, only pressure measurements are needed but the mode shapes must be extracted in terms of pressure and velocity.

In all cases, the use of FE allows to simply introduce the presence of a rigid object in the virtual acoustic volume. For example, as presented in Figure 1(a)(b), an object is introduced by removing its "acoustic footprint" (i.e. the volume occupied by the object is replaced by an empty space with Neumann's boundary conditions). Combining Neumann's boundary condition on the surface of the rigid object Σ_o ($\frac{\partial \phi_n(Q)}{\partial n} = 0$) for the VAV and the real boundary condition on a rigid surface ($\frac{\partial p(Q)}{\partial n} = 0$, i.e. null normal particle velocity) leads to $C_n = 0$ on Σ_o. Therefore, Eqns. (3) and (4) remain unchanged if the rigid object is considered in the FE model as explained previously and in [6].
This feature paves the way to an application of field reconstruction in real industrial environments, with frames, wires, machines, etc.

3. NUMERICAL STUDY

The numerical experiment presented here consists in a baffled simply supported plate radiating noise in a semi-infinite acoustic medium. As shown in Figure 2(a), the plate is partially masked by a parallelepipedal object considered here as perfectly rigid. The plate is 0.6 m long, 0.4 m wide, and 2 mm thick, and it is made of steel (Young's modulus E = 2.1×10^{11} Pa; density ρ = 7800 kg/m^3; Poisson's ratio ν = 0.3; damping η = 0.02). The plate is excited by a unit point force located at point (0.1; 0.1) m on the frequency band [100:1000] Hz. The masking object is 0.7 m long (longer than the plate) and 0.15 m wide (not centered along the width of the plate) and 10 mm thick. The masking object is located at a varying distance from the plate (1 cm, 5 cm, 10 cm and 15 cm).
The virtual acoustic volume is defined as a rectangular box surrounding the plate and completely containing the parallelepipedal object as presented in Figure 2(b). The identification patch mesh is regular with 600 patches (Figure 2(c)). The measurement patch mesh is discretized by 360 patches (Figure 2(d)). Finally, 600 randomly distributed positions of microphones have been chosen (Figure 2(e), no microphone is located in between the plate and the object).

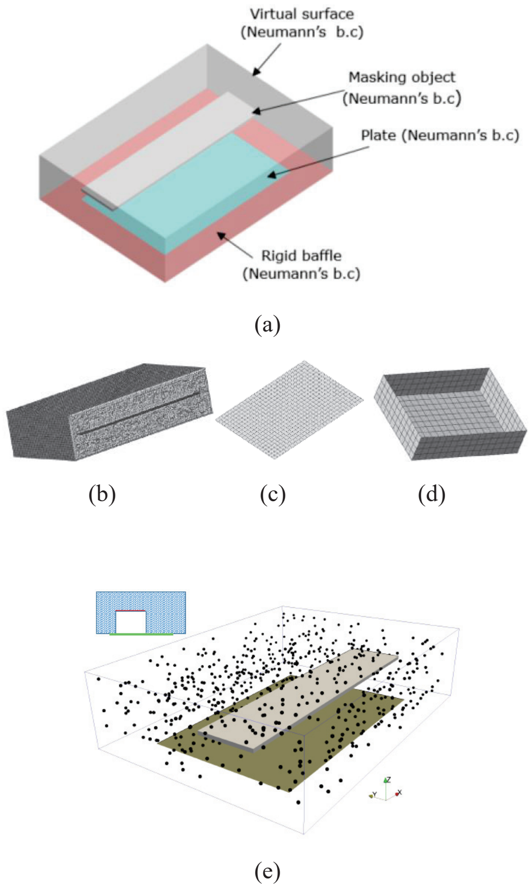


Figure 2. (a) system under study: a simply supported rectangular plate masked by a rigid parallelepiped; (b) FE mesh of the virtual acoustic volume; (c) identification patch mesh; (d) measurement patch mesh; (e) positions of microphones inside the virtual acoustic volume.

In this section, only the u-iPTF are presented. Using Eqn. (3) and pressure and particle velocity extracted from the numerical experiment (using MSC.Actran) and the virtual mode shapes of the VAV, one can compare the iPTF identification to the reference computation of the acoustic fields on the surface of the plate.
Figure 3 presents the reference intensity field compared to the one identified by iPTF in the presence of the masking object at a distance of 10 cm.

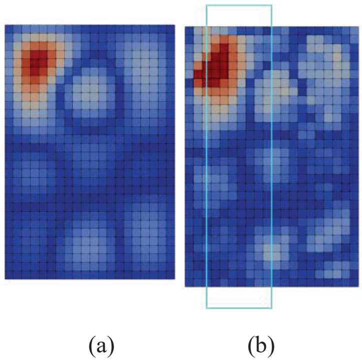


Figure 3. Intensity field at 332 Hz. (a) reference; (b) iPTF identification. Position of the masking object is represented by the rectangle.

As can be seen in Figure 3, iPTF method is able to accurately reconstruct the intensity field (which is obtained from the combination of identified pressure and particle velocity fields) even if the main zone of intensity is located in the "shadow" of the masking object. Again, it is important to underline that no microphone is located in between the plate and the object.

To evaluate the performance of the approach on a wide frequency range, the radiated acoustic power of the plate, identified from iPTF, is compared to the reference in Figure 4. In this figure, the acoustic radiated powers for each distance of the object (1 cm, 5 cm, 10 cm, 15 cm) are compared to the reference case and to the identified acoustic power without masking object (denoted in the figure as d0cm_w0cm).

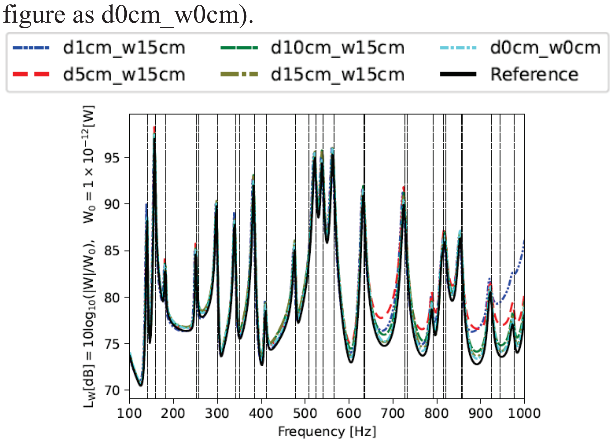


Figure 4. Estimated acoustic power for different distances from the masking object to the plate (1 cm, 5 cm, 10 cm, 15 cm) compared to the reference.

As demonstrated by Figure 4, the radiated acoustic power is well estimated by the iPTF approach even in the presence of a masking object. Everything happens as if the method were capable of erasing the presence of the object. At higher frequency and for small distance between the plate and the object, some discrepancies might appear, mainly due to the fact that, in that case, the presence of the obstacle modifies the vibratory behavior of the plate (not considered in the reference).

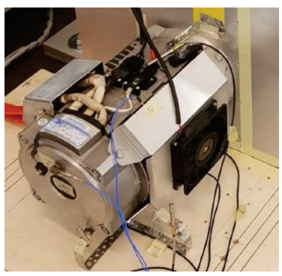
4. INDUSTRIAL APPLICATION

The industrial application consists in a SimRod e-motor, an electric motor that operates on the induction principle and is often used in fully electric or hybrid electric vehicles (FEV/HEV). The motor is mounted on a coupling unit. A load is applied to the SimRod e-motor using a "load motor". The system is rigidly mounted on a heavy frame uncoupled from the rest of the workshop. The acoustic environment is not anechoic and also integrates noise generated by electric cabinets.

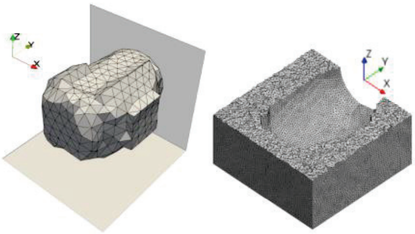
A picture of the SimRod e-motor can be seen in Figure 5(a). The identification patch mesh can be seen in Figure 5(b) (here represented along with the rigid surfaces of the heavy frame (planes). The corresponding FE model is shown in Figure 5(c)

To evaluate the performances of the iPTF method in presence of masking object, a rigid parallelepipedal object has been physically fixed close to the motor as can be seen in Figure 5(d). The corresponding FE model is presented in Figure 5(e). The measurement patch mesh is presented in Figure 5(f).

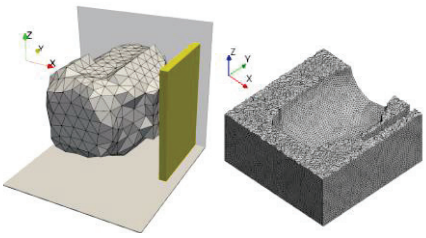
In this section, only the results obtained using m-iPTF (avoiding the use of PU probes) are presented. The two configurations, with and without the masking object are compared.



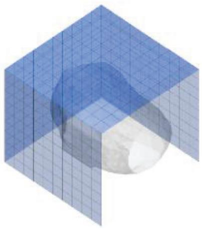
(a)



(b) (c)



(d) (e)

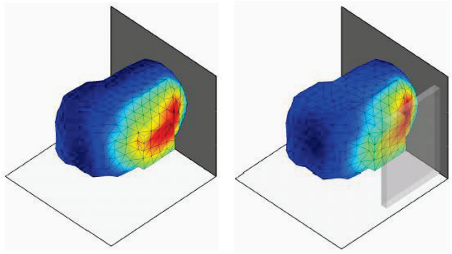


(f)

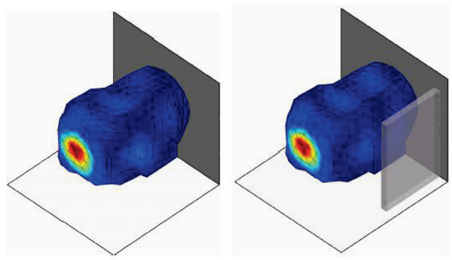
Figure 5. (a) picture of the SimRod e-motor (b) identification patch mesh; (c) FE mesh of the VAV without masking object; (d) position of the masking object; (e) FE mesh of the VAV with the presence of the masking object; (f) measurement patch mesh

An example of the comparison can be seen in Figure 6: the identified intensity fields obtained at 544 Hz and 1992 Hz are shown.

The results are really similar and the intensity fields at 544 Hz (mainly located in the "shadow zone" of the masking object) demonstrate that the iPTF approach can be used in really difficult conditions and provides a detailed characterization of the source under study.



(a) (b)



(c) (d)

Figure 6. iPTF identifications with (a and c) and without (b and d) a masking object in front of the electric motor at 544 Hz (a and b) and 1992 Hz (c and d).

5. ACKNOWLEDGMENTS

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