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NOISE SOURCE LOCALIZATION - COMPARISON OF DIFFERENT METHODS

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ABSTRACT

This paper presents a review of different methods developed in order to localize noise sources. Three methods are analyzed: i) Intensity technique. Initially developed to quantify the acoustic power, this technique is sometimes used to localize sources, ii) Acoustical holography. Based on a back propagation (by spatial Fourier transform), this technique increases the resolution by computation the acoustical field closer to the sources. It is very powerful with a great number of microphones, iii) Focusing technique. This last one has been first used for application on moving sources (measurement in farfield). It can be also used in nearfield and has an advantage when the number of microphone is reduced.

1 - INTRODUCTION

The noise source localization is a good information to understand noise emission and to optimize solutions in order to reduce the noise. The acoustic maps are a good support of discussion between engineers of the design department and the acousticians. Different techniques, developed in the last past 20 years, are reviewed hereafter.

2 - INTENSITY METHOD

The intensity measurement method is well known: it has been developed 20 years ago in order to quantify total acoustic power. It consists in enclosing surface and measuring the intensity on this closed surface. The formulation is:

$$W = \int_S I_n.ds$$

This computation is good in common room (no requirement of anechoïc or reverberant rooms) and even if other sources exist outside the surface.

The method can be extended to a plane surface, if the surface is large enough to be considered as an infinite area in front of the acoustical source.

In a second time, this method has also been used in order to localize noise sources and to quantify partial power: the whole surface is divided in several areas and the energies going through these areas are computed. We will see that when the sources are in the same plane, the error of this method is important.

3 - ACOUSTICAL HOLOGRAPHY

The formulation for acoustic holography is now well known. We give here its principles. The processing to compute the field in a plane from the measurement with an array in another plane can be divided in 3 steps.

⇒ decomposition of the acoustical field on the array by spatial Fourier Transform:

$$p\left(k_x, k_y\right) = \int\int P_{array}\left(x, y\right).e^{+j.\left(k_x x + k_y y\right)}.dx.dy$$

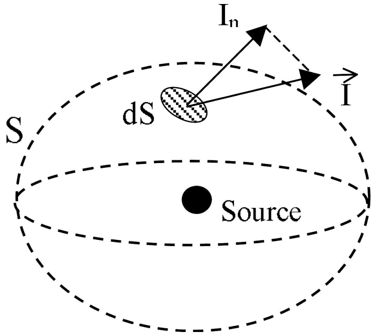


Figure 1.

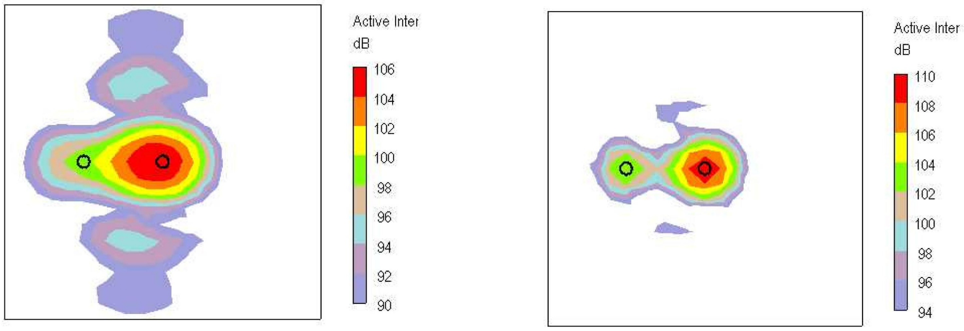
The spatial spectrum will be noted S.
⇒ backpropagation of the different waves up to the computed plane:

$$S_c\left(k_x, k_y\right) = p\left(k_x, k_y\right) \cdot e^{-j \cdot k_z \cdot d}$$

with d the distance between the array and the computed plane.
The value k_z is dependent of the values of k_x and k_y, with the dispersion relation. The backpropagation operator can take two forms:

- $k_x^2 + k_y^2 \leq k_0^2$, then $k_z = \sqrt{k_0^2 - k_x^2 - k_y^2}$ and $S_c\left(k_x, k_y\right) = p\left(k_x, k_y\right) \cdot e^{-j \cdot k_z \cdot d}$. The waves are propagative ones,
- $k_x^2 + k_y^2 > k_0^2$, then $\left|k_z\right| = \sqrt{k_x^2 + k_y^2 - k_0^2}$ and $S_c\left(k_x, k_y\right) = p\left(k_x, k_y\right) \cdot e^{-\left|k_z\right| \cdot d}$. The waves are evanescent, with an exponential decay from the source.

The interest of this method is to increase the resolution by comparison to the intensity method. The figure 2 shows a comparison for two sources distant of 20 cm at 1250 Hz. The distance between the sources and the array is 10 cm. The measurement is done for a 21 ×21 points array, the distance between each point is 4 cm.



(a): Intensity on the array. **(b):** Backpropagated intensity.
Figure 2: Comparison of intensity and acoustical holography.

The two sources are not separated on the intensity measurement. The holography, by increasing the resolution, allows seeing the two sources; it can be noted that the right source is higher than the left one (about 6 dB).
A natural consequence of this better resolution is that the capability of acoustical holography is also better to quantify partial power.
On the figure 3, the global power of the whole surface is compared to the partial power of the 200 ×200 mm area centered on the source, calculated on the array and on the back-propagated source surface (20 cm each other). The partial power calculated on the source surface is under-estimated by 2 dB from the global power on the 1/3$^{\text{rd}}$ octave 800 to 3150 Hz, whereas the error is more than 8 dB for intensity measurement.
The Acoustical holography is now often used in automotive industry and the goal is to increase more and more the resolution. This goal has two consequences:

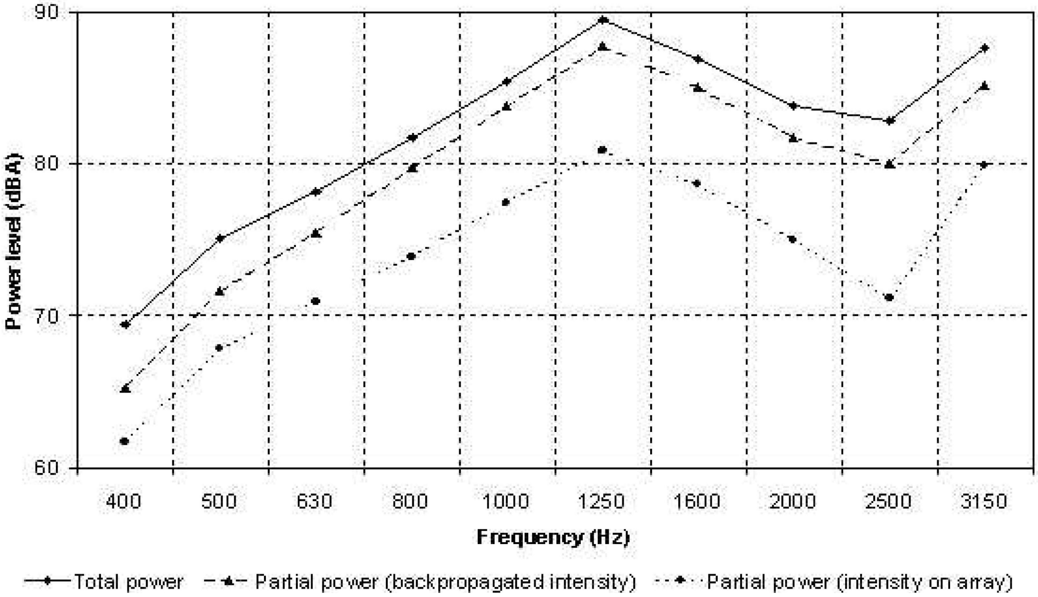


Figure 3: Partial power estimation.

- The sampling distance decreases (now currently 2 or 3 cm) and the total number of measured points increases up to several thousand. This point requires a quite automated system. With such a system, the duration of the measurement is something like 10 minutes for one face of an engine.
- The algorithms used in the processing are important to increase the resolution without divergence. MICROdB used a Wiener filter. With a good choice of measurement parameters, it allows to have a resolution equal to $2p$ (p sampling distance) in all the frequency range of interest (400-4000 Hz).

The figure 4 presents the example of the measurement of acoustic transparency of a vehicle. The measurement is carried out by reciprocity: a loudspeaker is placed at the ear of the analyzed passenger and the measurement is performed outside the vehicle. The sampling distance is 3 cm and the total number of measured points is 2016. The accuracy of the method can be underlined.

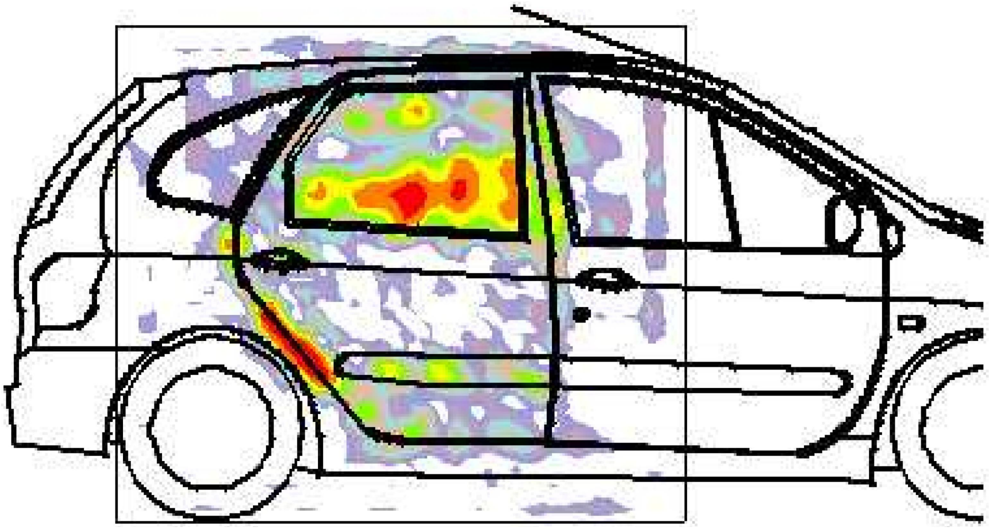


Figure 4: Hologram 1250 Hz.

4 - FOCUSING TECHNIQUE

This technique has been first developed for submarine or environmental applications. The array is placed in farfield and the technique allows obtaining the direction of the source. The principle is very simple: for each point of computation, the signals provided by each microphone are added with a delay corresponding to the propagation. The comparison between acoustical holography and focusing depends of the point of view that we take. Three cases are distinguished.

4.1 - Comparison between acoustical holography in nearfield and focusing in farfield

In that comparison, the resolution of acoustical holography is obviously better. The resolution of acoustic holography is equal to $2p$ (p: sampling distance) and the resolution for focusing is something like $\lambda/2\sin\alpha$. In high frequency range, the results are similar, but in low frequency range acoustical holography is quite better. For example, the resolution at the frequency 500 Hz can be 6 cm for holography (with good algorithms) and 68 cm for focusing (when the size of the array is equal to the distance between the sources and the array)!!

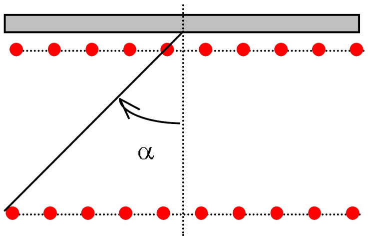


Figure 5.

4.2 - Comparison between acoustical holography and focusing in nearfield

There is here a difficulty in the algorithm used for focusing because the distance between the computed point and the different microphone are quite different. With a good solution to this problem, the results obtained with the two techniques are very similar.

4.3 - Comparison between the two techniques with a low number of microphones

When the sources are impulsive ones, it is necessary to do the processing in time domain and to have all the microphones at the same time. So, the number of microphones is limited: the larger actual systems have about 100 microphones. In that case, the Spatial Fourier Transform used in holography is not well adapted in relation with the poor number of point in each direction. The focusing technique is better; it allows multiplying by 2 the frequency band of the technique. With 100 microphones (sampling distance of 7 cm), acoustical holography is operating in the 700-3000 Hz and focusing can be used between 500 and more than 4000 Hz; this point has an operational interest.

When the number of microphones is very low, acoustical holography can not be used and focusing continues to give results in a limited frequency band. For the engine application, an array with 15 microphones (see below) gives results in the frequency band 700-2100 Hz. An example of result is given on the figure 6.

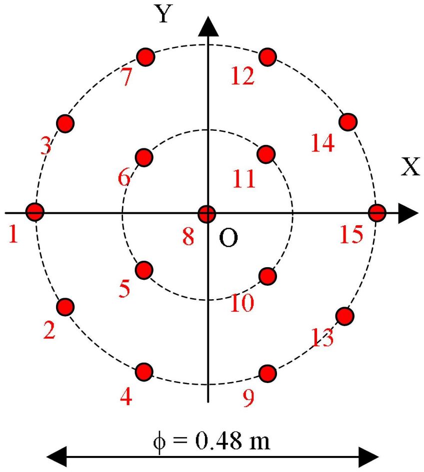


Figure 6(a): Array arrangement.

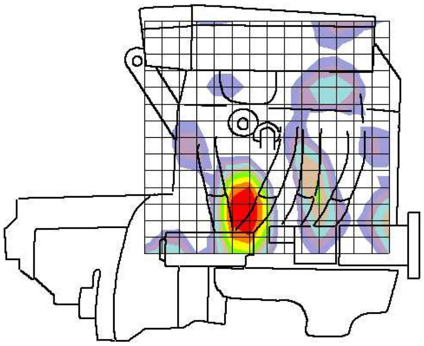


Figure 6(b): Map with focusing technique.

5 - GLOBAL METHOD FOR ENGINE ANALYSIS

As conclusion, Acoustical Holography and focusing are two interesting approaches in order to localize noise sources. To analysis engine noise, a global approach in two steps uses their complementarily:

- First, a focusing technique is used in run-up conditions; it allows to do a rough localization on a large range of speeds, the critical speeds can be identified,
- In a second step, an acoustical holography technique permits to precise localization at different constant speeds.