

# inter-noise 97

Budapest – Hungary, August 25-27

## PRACTICAL ASPECTS FOR ACOUSICAL HOLOGRAPHY.

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### 1- INTRODUCTION

This paper deals with Acoustic Holography, and more precisely with its implementation in HOLOdB software. After reminding principles which are now well-known, the objectives of it are :

- to examine the practical aspects in the using of acoustic holography,
- to show interests of acoustical holography by comparison with vibration and intensity measurements.

From measurements with a planar array, acoustical holography allows to compute the acoustic field in a tangent plane to the source and, by this way, to focus the « hologram ». This processing follows different steps :

- decomposition of the sound field in plane waves by spatial Fourier transform,
- back propagation of waves (propagative and evanescent) up to another plane,
- computation of the field on this plane by inverse spatial Fourier transform.

The main difficulty of this processing is to take into account evanescent waves. Using a Wiener filtering is the best solution to increase the resolution without divergence.

The quality of the results is strongly dependant of the good choice of the parameters (of the technique) like sampling of the sensors on the array, distance between the array and the source, size of the array in relation with the size of the source, parameters of the Wiener filter.

This technique is complementary with intensity method and vibratory measurements. Its advantages are the following :

- noise sources localisation. It can be proved that acoustical holography, with its capability to compute in an other plane than the measured one, is quite better than intensimetry for this function.
- acoustical radiation of two object can be different with the same vibration level. For example, in an engine, the radiation efficiency of covers is lower than the one of the block. In other words, the radiation of the covers are lower for the same vibration level.

## 2- PRINCIPLE

The formulation for acoustic holography is now well known [1]. 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 :

$$p(k_x, k_y) = \iint P_{array}(x, y) \cdot e^{+j(k_x x + k_y y)} \cdot dx \cdot dy \quad \text{The spatial spectrum will be noted } S.$$

⇒ backpropagation of the different waves up to the computed plane :

$$S_c(k_x, k_y) = p(k_x, k_y) \cdot e^{-j k_z \cdot d} \quad \text{with } d \text{ the distance between the array and the computed plane.}$$

The value  $k_z$  is dependant of the values of  $k_x$  et  $k_y$ , with the dispersion relation. The backpropagation operator can take two forms:

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

It can be pointed out that the inverse operator with evanescent waves is unstable. So two ways can be taken to backpropagate :

- take into account only the propagative waves.
- take into account the evanescent wave in order to increase the resolution. To eliminate the risk of divergence of the operator, the best solution is to use a Wiener filter [2]. Its implementation in HOLOdB is the following :

$$\left\{ \begin{array}{l} W_{opt}(k_x, k_y) = \frac{g^*(k_x, k_y) \cdot \gamma_p(k_x, k_y)}{\gamma_g(k_x, k_y) \cdot \gamma_p(k_x, k_y) + \gamma_B(k_x, k_y)} \\ g = e^{j k_z \cdot d}, \text{ the operator of propagation.} \\ \gamma_g = e^{j k_z \cdot d} \cdot e^{-j k_z \cdot d}, \text{ its spectral density.} \\ \gamma_p, \text{ the spectral density of the acoustical field.} \\ \gamma_B = \frac{\gamma_p}{R_{SIB}}, \text{ the spectral density of the noise.} \end{array} \right.$$

⇒ the last step consists in computing the pressure in the computed plane by inverse spatial Fourier Transform :

$$P_c(x, y) = \iint S_c(k_x, k_y) \cdot e^{-j(k_x x + k_y y)} \cdot \frac{dk_x}{2\pi} \cdot \frac{dk_y}{2\pi}$$

### 3- EXAMPLES OF RESULTS

To visualise the interest of holography, let's take the example of measurement with two loudspeakers, each one with two actuators : a boomer and a tweeter. Measurements have been done for a 17\*16 array. The distance between two points is 4 centimetres and the distance between the array and the loudspeakers is 10 centimetres.

Figure 1 and 2 show the pressure on the array and the pressure computed in a plane tangent with the loudspeakers for the 1/3 octave 2500 Hz. The processing is done without evanescent waves. The maps are presented with 16 dB of dynamic (difference between colours black and white). On the measured map, it is impossible to determine the number and the position of the sources. Four sources appear clearly on the backpropagated map. It can be noted that the emission of the tweeters is more important than the emission of the boomers in this frequency range.

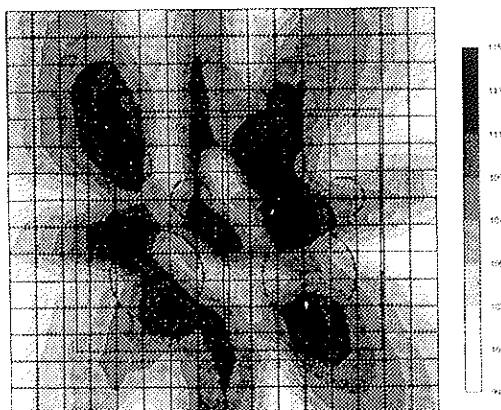
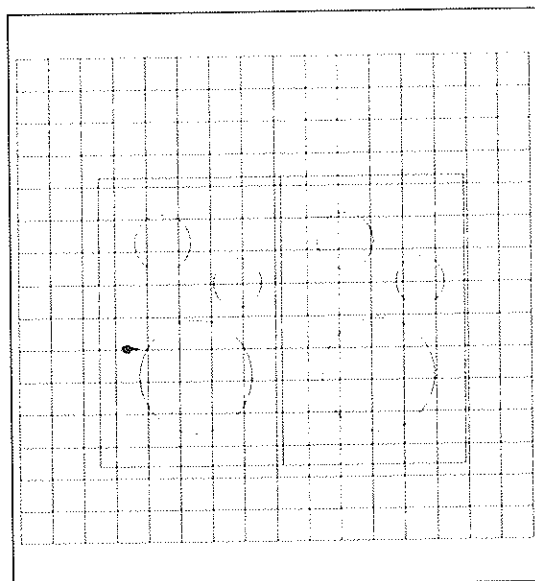


Figure 1 : measured pressure  
1/3 octave 2500 Hz

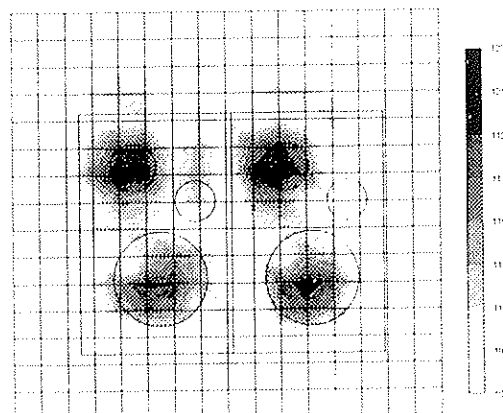


Figure 2 : backpropagated pressure  
1/3 octave 2500 Hz

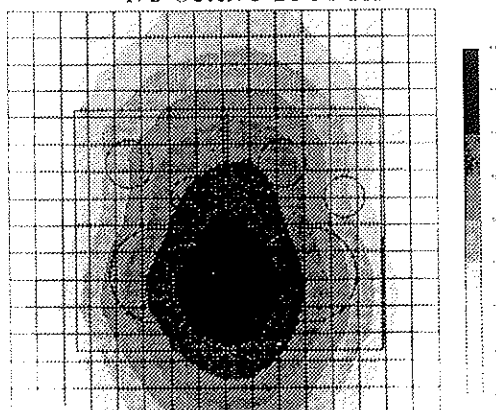


Figure 3 : measured pressure  
1/3 octave 800 Hz

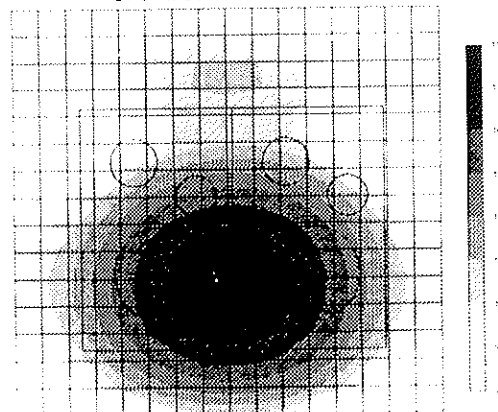


Figure 4 backpropagated pressure  
1/3 octave 800Hz

In low frequency range the resolution (without evanescent waves) decreases. Thus, the figures 3 and 4 show the same results in the 1/3 octave 800 Hz. A quick analysis concludes to one source, placed between the 2 boomers.

Using evanescent waves is then useful to increase the resolution. The figure 5 shows the results obtained by using a Wiener filter. The radiation of the two boomers can be seen. In this frequency range, the radiation of the tweeters is negligible.

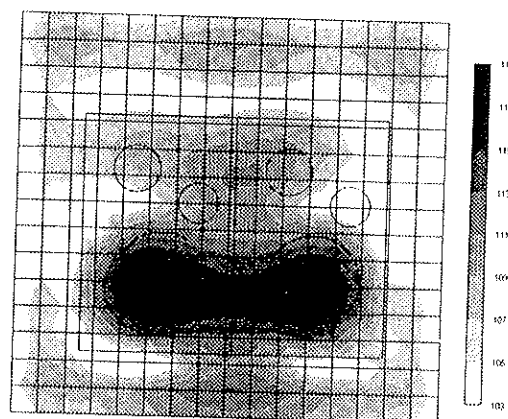


figure 5 : backpropagated pressure with Wiener filter 1/3 octave 800 Hz

#### 4- PRACTICAL ASPECTS

This paragraph is devoted to give a guideline to fix the different parameters of the technique.

##### Sampling on the array.

The distance between two microphones is defined with the relation of the SHANNON theorem. This distance must be lower than half of a wavelength. The wavelength to be considered is the smallest (including evanescent waves). In practice it is sufficient to take the acoustical wavelength at the high frequency. For example, if the highest frequency of interest is 4000 Hz, the sampling on the array must be 4 centimetres.

##### Size of the array.

Two things have to be said on that point. From a scientific point of view, the size of the array must be larger than a wavelength. If the lowest frequency of interest is 500 Hz, the minimal size of the array is 68 centimetres. From a practical point of view, the size of the array must be twice the size of the source. In many cases, this last recommendation cannot be covered. HOLOdB integrates a specific processing to minimise the border effect (spectral interpolation and Adhoc window) [3]. In any case, it is not recommended to use backpropagation if the level of the measured pressure is maximum on the border of the array.

##### Distance between the array and the source

The first general argument is to put the array as close as possible to the source and the practical aspects fix it. It must be pointed out that, from the scientific point of view, this distance must be superior to the sampling on the array.

## 6- COMPLEMENTARITY WITH VIBRATORY MEASUREMENT

Many acoustical problems can be solved only with vibratory measurement. The aim of this paragraph is to show which complementary information can be given with holography. Three points can be mentioned :

⇒ *measurement is easier*. This is an advantage if there are many measured points and more particularly for rotating objects,

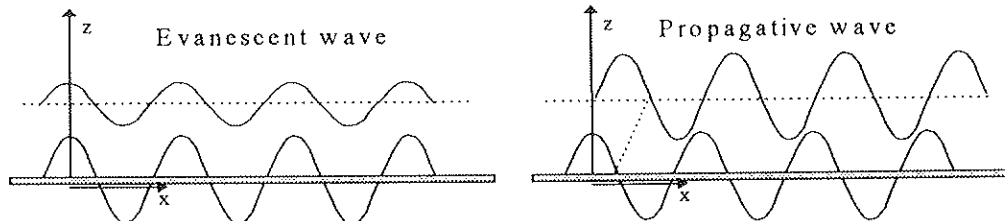
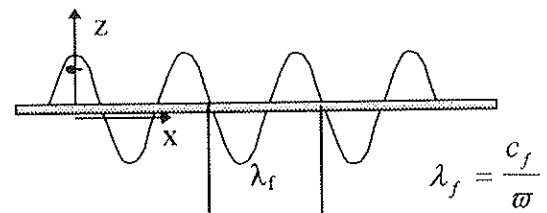
⇒ *radiation efficiency*. The radiation efficiency of parts of a structure can be different. Let us take the example of a plate, on which a bending wave at the frequency  $f$  is propagating. For this wave, the plate is a dispersive medium : the celerity varies with the frequency approximately as :

$$C_f = A f^{1/2}$$

A frequency, name critical frequency, separates the frequency domain in two parts :

$f < f_c$  : evanescent domain. Acoustic waves decrease exponentially from the structure.

$f > f_c$  : propagative domain. The noise is radiated in farfield.



For the same vibratory level, a difference more than 20 dB can exist in the farfield radiation. This argument is important when a source is heterogeneous. It is the case for an engine. The covers, like oilpan, have a low radiation efficiency by comparison with the block.

⇒ *airborne born noise and structureborne noise*. In the same way than previously, the radiation efficiency for airborne noise is higher than the one for structureborne noise. So, if only vibratory measurement are done, structureborne is privileged. It can be a problem for structure in new material, that's why it is known that airborne noise is not negligible.

[1] JD MAYNARD, EG WILLIAMS. « *Nearfield acoustic holography : theory of generalised holography and the development of NAH* ». JASA 78(4) October 1985.

[2] JY DERMATHEOSSIAN. « *Problème inverse régularisé pour l'holographie acoustique en champ proche : applications en milieu perturbé* ». Thèse université Paris 7 septembre 1994.

[3] JL CHAURAY, Bernard BEGUET, Jan LEURIDAN. « *Localisation system for acoustics sources* ». Euro.Noise'95 Lyon march 1995

[4] JC PASCAL. « *Caractérisation expérimentale du champ rayonné. Intensimétrie et antennes acoustiques* ». In « *Rayonnement acoustique des structures* » 1988 Eyrolles