Method for analyzing transient noise based on instantaneous intensity measurements

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Abstract: Analysis of random and transient noises (i.e. squeak and rattle phenomena or clicks caused by the expansion of electrical heaters) cannot be solved properly with conventional methods based on spectral analysis of acoustical pressure, because the Fourier transform involves time averaging of very short events and the noise level cannot be correctly estimated. For this main reason, the CTTM has developed a noise analysis method in the time domain by measuring the instantaneous acoustic intensity using an antenna of three sound intensity probes (p-p probes). This method uses the Hilbert transform to express the instantaneous complex intensity where real part represents the propagative component (active intensity). The localization of transient noise is obtained by a triangulation method. The magnitude is calculated by taking into account the location of the noise.

This paper presents the theoretical basis of the instantaneous intensity analysis method and shows results of experimental qualifications of instantaneous intensity measurements and localizations of impulse type noises. The test rig described uses miniaturized intensity probes and an analysis and processing system developed by CTTM.

Keywords: Instantaneous complex intensity, localization, intensity probe, transient noises

1. Introduction

This work is in the context of unsteady and impulsive unexpected noises like squeak and rattle, screeching seals. Currently, the techniques to measure and locate these types of noises are limited. Methods using FFT analysis technics are not suitable because of the necessary time averaging. Different techniques such as unsteady holography which is based on decomposition in wave numbers [1,2] could be interesting, but experience shows that the measurement range is limited and the frequency band reduced and it requires a lot of microphones. Other imaging techniques have been used to analyze non-stationnary sources [3] but implementation is complicated for a low efficiency.

In other areas, the use of instantaneous intensity [4,5] allows temporal measurements of sound intensity in standard measurement conditions (not too reverberant media). It is an adapted tool for the strongly unsteady noises analysis. Associated with a localization method based on triangulation, this technique can achieve accurate mapping of impulse noise. This is the subject of this paper.

2. Description of the method

The proposed method is based on the use of a three intensity probes antenna arranged to form a triangle in a plane parallel to the measurement plane (figure 1). The measure of instantaneous intensity with each probe is used firstly to locate the impulse noise with a triangulation method and also to estimate their acoustic power level.

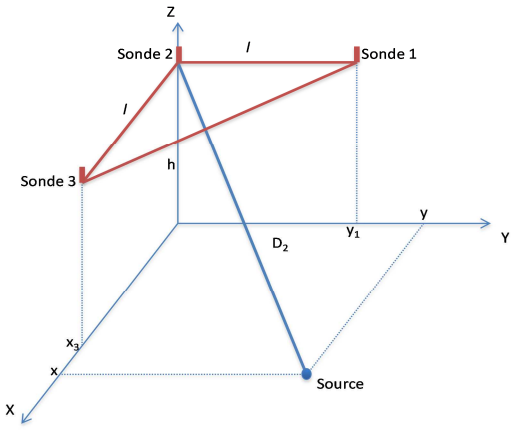

Figure 1 : description of the intensity probe antenna

To fix the dimensions of the assembly, the probes are separated by l = 25 cm and the antenna is placed at h = 30 cm from the source plane. In this configuration, the area "observed" by the antenna is of the order of 1 m².

To realize all the measurements we use the CTTM miniaturized probe (figure 2). The conception of which is of pressure-pressure type with a tandem mount of the two microphones (figure 3).

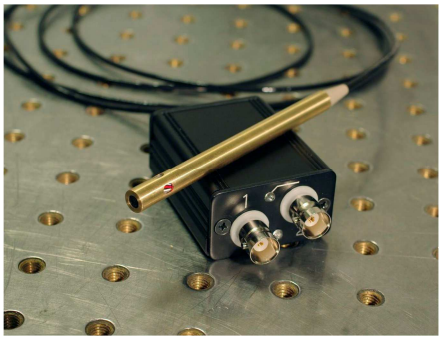

Figure 2 : The miniaturized probe of CTTM

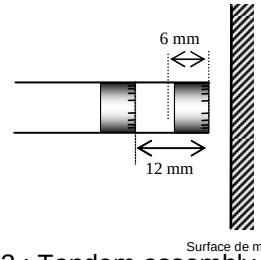

Figure 3 : Tandem assembly of the probe

3. Localization method

3.1 Theory

The localization method of the noise source is a method of triangulation which analyzes the delays between the signals measured by three intensity probes of the antenna. The distance d traveled by the sound wave until each probe can be expressed in function of the speed of sound c and the propagation time Δt :

$$d = c\Delta t = c(t - t_0) \quad (1)$$

Where t_0 is the emission time of the source and t is the detection time recorded by the probe.
According to the figure 1, the distances between the source and the probes can be expressed as follow:

$$d_1^2 = (x - x_1)^2 + (y - y_1)^2 + h^2 \quad (2)$$

$$d_2^2 = (x - x_2)^2 + (y - y_2)^2 + h^2 \quad (3)$$

$$d_3^2 = (x - x_3)^2 + (y - y_3)^2 + h^2 \quad (4)$$

Where x, y and z corresponds to the location of the source (z=0), and h is the distance between the source and the probes plane.
From the measured instantaneous intensity, an iterative solution method of the equations system (1),(2),(3),(4) allows to determine t_0 and the location x et y of the source.

3-2 Experimental validation

To validate the localization method, tests were conducted by making manually impacts on a wooden plate at known positions. The analysis by the triangulation method is then used to determine the source location and the results are compared to the reference locations.
An example of measuring instantaneous intensity is shown in figure 4 and 5. It represents 6 impulse noises of varying intensities. Figure 5 is a zoom of the fourth impact. The different delays are measured by comparing the three signals recorded by each intensity probe. The location of each impact is then calculated from these delays. Figure 6 compares the experimental impacts localization to the theoretical positions. Overall, the localization is performed with an accuracy of the order of ±1.5 cm along the two axes for a total area of about 1 m². Given the different uncertainty sources of the experience (positioning sensors, precision of the impact ...) this result is very satisfactory.
It should be noted that this demonstration is based on point and unmasked sources (monopole source). More complex cases of diffuse or distributed sources may probably be more difficult to treat.

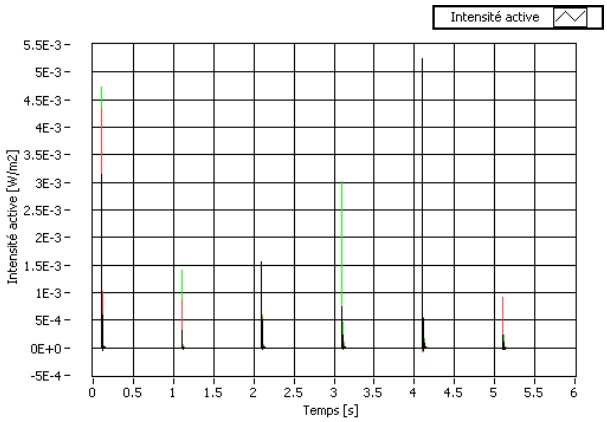

Figure 4 : Measured instantaneous intensity of 6 manual impacts on a wood plate

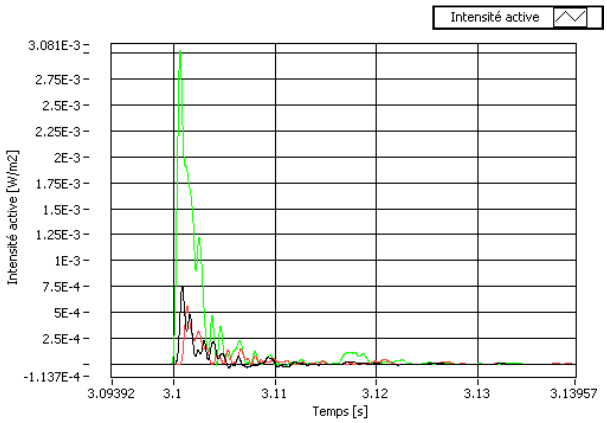

Figure 5 : Zoom of the fourth impact

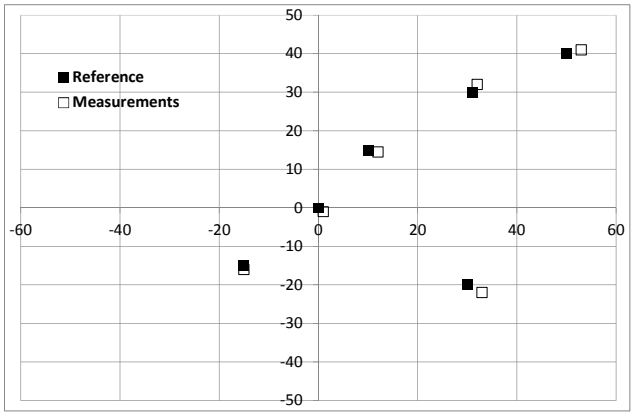

Figure 6 : Example of measured impacts locations compared with the reference locations

4. Measurement of instantaneous intensity

4.1 Theory

Sound intensity I is defined by the product of the acoustic pressure p_a and the acoustic velocity v_a :

$$I = p_a v_a \quad (5)$$

In time domain, the instantaneous intensity has been defined in different ways, especially in terms of complex instantaneous intensity by Heiser [4] who defines the active (I) and reactive (J) components using the Hilbert transform:

$$I = \frac{1}{2}\left(p_a(t)v_a(t) + \tilde{p}_a(t)\tilde{v}_a(t)\right) \quad (6)$$

$$J = \frac{1}{2}\left(\tilde{p}_a(t)v_a(t) - p_a(t)\tilde{v}_a(t)\right) \quad (7)$$

Where $\tilde{v}_a$ et $\tilde{p}_a$ are the Hilbert transform of v_a and p_a.

For our application, we use only the active intensity, which describes propagating acoustic waves.

With a p-p probe (figure 3) the acoustic velocity is computed by integrating the acoustic pressure gradient between the two microphones:

$$v_a = \frac{1}{\rho \Delta x}\int (p_2 - p_1)dt \quad (8)$$

Where Δx is the distance between the microphones and ρ the air density.

4.2 Intensity probe directivity

The use of intensity probes in our antenna allows to estimate easily the level of the detected noise in terms of intensity if we take into account their directivity. The position of the source by triangulation method gives the location information of the probes relative to the noise source. From these data, the directivity is takes into account to determine the acoustic intensity of the noise. Then, it is possible to calculate an estimate of the acoustic power of the source assuming for example a propagation of a monopole source in an open space (intensity distributed over a hemisphere).

The intensity probe directivity used in this study was measured. The geometry of the CTTM probe (tandem mounting) provides a directivity slightly different from the conventional probe (mounting face to face with spacer). An example of this directivity measured at 1000 Hz is represented on Figure 7. A drop in measured intensity appears for an angle of 85°, and the beginning of a decrease from 40°. These results are found for all frequencies in the range useful for analysis in time domain [400 Hz - 4000 Hz].

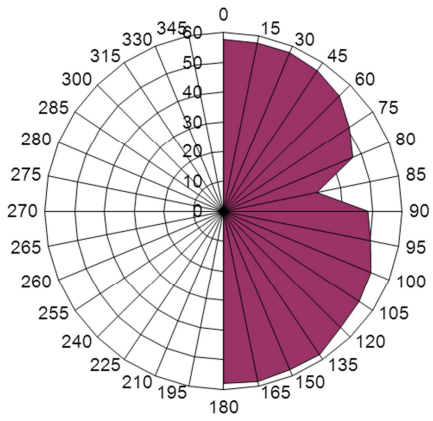

Figure 7 : Directivity pattern at 1000 Hz

Therefore, it may be considered for angles less than 40 ° that the intensity measurements are not affected by the directivity of the probe. Given the size of the antenna and its location relative to the source area, it appears that regardless the source location, there is always a probe with an angle between its axis and the direction of the source less than 40°.

Thus, the source intensity will always be directly measurable with one of the three probes.

4.3 Experimental validation

To validate the sound power estimation from the instantaneous intensity, an experimental device is used to perform reproducible measurements with a high-speaker source in free field conditions in semi-anechoic chamber (figure 8). Validations involves comparing the sound power level of the impulse type noise source calculated in two ways: from the sound pressure either from the acoustic intensity.

The sound power level L_w is calculated from the intensity level L_I and the surface S of the hemisphere of radius d :

$$L_w = L_I + 10\log_{10}(S) \quad (9)$$

The acoustic intensity level is computed in two ways:

- From the acoustic pressure p with the assumption of free field propagation : $I = p^2/\rho c$
- From direct instantaneous intensity measurement (§ 4.1)

The probe is placed perpendicular to the source plane in different locations defined by the distance to the source and the angle α of its axis with the direction of the source (figure 8). Figures 9 and 10 compare the two ways of measuring acoustic power in function of the angle α for the probe at 10 cm or

30 cm of the source plane. It is clear that for less than about 40°, the differences between the two powers are lower than 1 dB. For greater angles, differences become significant because of the directivity effect of the intensity probe. However, in the geometry where the antenna is located at 30 cm from the source plane, any angle in an area of 1 m² can be measured with less than 40 °. It can then be considered that the acoustic power measurement from the instantaneous intensity does not depend on the angle α.

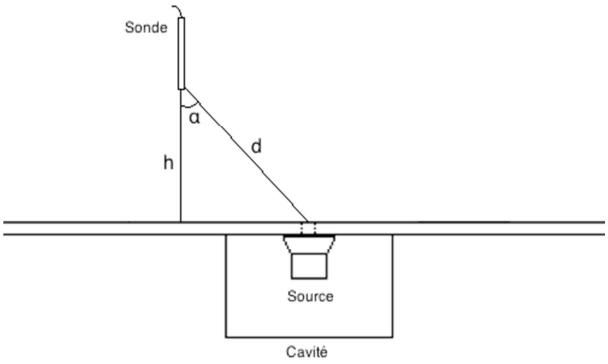

Figure 8 test rig for reproducible measurements

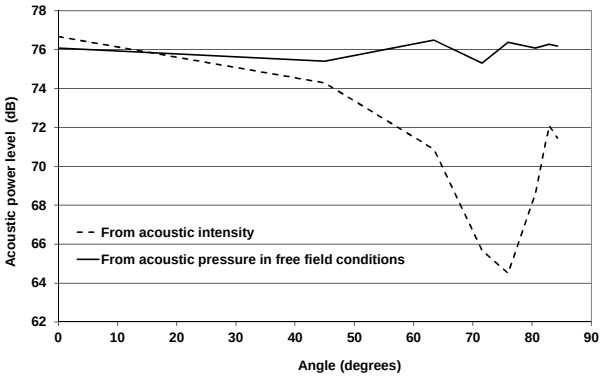

Figure 9 : at 10 cm of the source plane

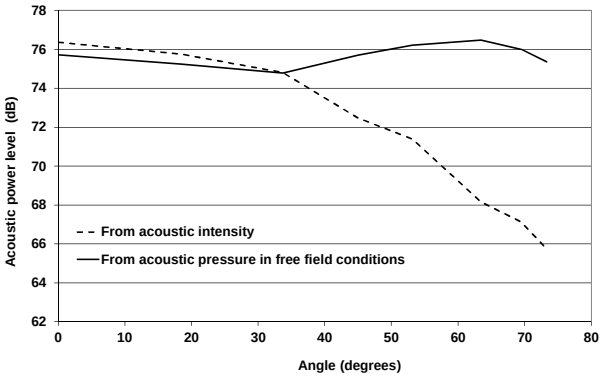

Figure 10 : at 30 cm of the source plane

5. Conclusions

The study presented in this paper has shown the ability to localize and characterize transient point sources with an antenna of three intensity probes. It was shown that such an antenna located at 30 cm from the source plane can cover an area of about 1 m².

The advantages of such a method are given by the benefits of the sound intensity metrology that permits measurements over a wide frequency band with a wide range of measurements. In addition, the technique is suitable for any standard media in which the only sound pressure measurement is not enough to determine a sound power.

The method is well suited to the case of point sources like monopole acoustic source. More complex cases of diffuse or distributed sources should be tested to evaluate the tolerance of the method.

Such a method could be used to describe the unexpected noise of automotive vehicles (squeak and rattle, screeching seal...) or in other areas such as for detecting expansion noises of electric heaters for example.

6. References

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