Scanning the sound field from uncorrelated sources

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In near field acoustic holography the sound field is scanned near the surface of the vibrating object; from these measurements the vibration of the structure can be calculated. In the case of correlated sources one reference signal is sufficient. When incoherent sources are present the separation of the different sound fields is difficult. Using, instead of a pressure microphone, a particle velocity sensor from which the particle velocity vector is calculated the incoherent sound fields can be separated.

1 Introduction

In near field acoustic holography (NAH) [1,2] the sound field is measured near the vibrating object. A special form is the planar acoustical holography, PNAH, the scan is done in a plane near the object. Measurement of the sound pressure [3] as well as the particle velocity have been published [4]. In the case of correlated sound sources one reference sensor can be used. When the sound sources are not correlated the technique with one reference signal does not work; the number of reference signals should be at least equal to the number of uncorrelated sources. Suppose there are two uncorrelated sound sources A and B. When the distance between A and B is relative large the reference signal for source A is taken in the neighbourhood of A, and vice versa for B. However, when near source A the contribution of source B to the total sound field is considerable this method will not work. A number of papers have been published [5..10] discussing the problem of multi-, incoherent, sound sources in acoustical holography; as sensors pressure microphones were used. In this study we used a three dimensional particle velocity sensor [11], with which the three components (x,y,z) of the particle velocity vector can be measured. Since the particle velocity is a vector, and not a scalar like the sound pressure p, the particle velocity from source A has a well defined direction, v⊥A. As a consequence, in a direction perpendicular to this direction v⊥A, the particle velocity from source A vanishes and only a contribution from source B is measured. Similarly there is a direction where the particle velocity component from source B vanishes and only the contribution from source A is measured. Define these two directions as v⊥A and v⊥B. In order to find these two directions use is made from the property that the cross correlation between the particle velocities in the directions v⊥A and v⊥B vanishes, since source A and B are uncorrelated and the measured signal in the direction of v⊥A contains only the signal from source B, and vice versa the signal in the direction of v⊥B only the signal from source A. The x-y distribution of e.g. the pressure, caused by source A, pA(x,y), can then be found from the cross correlation between p(x,y) and v⊥B; the contribution of pB(x,y) in this cross correlation with v⊥B vanishes since v⊥B does not contain the B-signal. Also the phase distribution can be determined from the (complex) cross correlation of p(x,y) and v⊥B. In a similar way the pressure distribution caused by source B can be found from the cross correlation of p(x,y) and v⊥A. Knowing the pressure distribution of pA(x,y) and pB(x,y) the known procedure [1,2] for obtaining the vibration structure of the source can be used.

2 Experiments.

The experimental set up consists of a plate with dimensions 30*22* 3 cm³, with near the centre of the plate two holes with a diameter of about 0.3 cm, separated from each other by about 4 cm; the holes are denoted as A and B. Two loudspeakers were clamped at the back of the plate, at the positions of the two holes A and B. Low frequency noise in a 1/3 octave band with centre frequency of 125 Hz was used as excitation; the cross correlation between the two noise signals averaged over a time of 0.1 seconds and normalized to the square root of the auto-spectra was about 0.04 (auto spectrum= p^2 rms). The measuring probe consists of three microflows, oriented in perpendicular directions [11] and a small (pressure) microphone. A x,y scan at a distance z=2 cm from the plate (z-direction perpendicular to the plate) was done in 16*16 points, with steps of 0.5 cm; the scanned area was thus 8*8 cm². From a rough interpretation of the measured data of p and vz it was concluded that the source A was in the region x=2 cm, y= 3.5 cm and source B in the region x=6 cm and y=3.5 cm (the scanned area is in the centre of the plate and in the first quadrant of the x-y coordinate system, with the lower corner at x=y=0). The region x=4 cm and 0.5<y<5.5 cm was taken to detect the direction of v⊥A and v⊥B.
3 Experimental results.

From the measured in plane particle velocity components directions of \( v_{\perp A} \) and \( v_{\perp B} \) have been deduced. The procedure we used is probably not the best- or in terms of computer time, the most optimum, procedure; it is straightforward algebra and is of almost no interest from a point of view of acoustics. It is therefore reproduced in the appendix. Take a point \((x_1,y_1)\), with \( x_1=4 \) cm and \( y_1=1.5 \) cm, the solution for \( v_{\perp B} \) is \( v(\alpha_2) \) with \( \alpha_2=130.9 \). The sound pressure and particle velocity in the perpendicular direction \( v_z \) from source A can then be found from the cross correlation of \( p(x,y) \) (or \( v_z \)) and \( v(\alpha_2) \). For a scan in the x-direction almost above the two sources \( y \approx 3.5 \) cm) the results are shown in figure 1. The points denoted as (*) represent the (auto-spectra)\(^{1/2}\) of \( p(x,y) \), divided by the value of the (auto spectrum)\(^{1/2}\) of \( p(x_1,y_1) \). The points denoted as (+) are from the cross correlation \( CC p(x,y) v(\alpha_2) \), normalized to the product of the (auto-spectra)\(^{1/2}\) of \( p(x_1,y_1) \) and \( v(\alpha_2) \).

The points denoted as (o) and (.) relate to a second experiment where only source A was excited by noise (source B was switched off). The points denoted as (o) are from the CC \( p(x,y) \cdot v(\alpha_2) \) normalized to the product of the (auto-spectra)\(^{1/2}\) of \( p(x_1,y_1) \) and \( v(\alpha_2) \); the values for \( v(\alpha_2) \) are of course taken from the experiments with two sources on.

The normalization is done in order to make a comparison between the auto spectrum of \( p(x,y) \) with dimension (Pa)\(^2\) and a cross-correlation of CC \( p \cdot v \) with dimension Pa.(m/sec) possible, and to eliminate the differences in sensitivities of the p-sensor and the v-sensors.

Figure 2 show similar results for the z-component of the particle velocity, \( v_z \), (the points *, +, o and . refer to the same situations as in figure 1; the normalization is similar, except that \( p(x_1,y_1) \) is replaced by \( v_z(x_1,y_1) \)). Figures 3 and 4 show the results for a x-scan at about \( y = 0.5 \) cm, thus \( 2 \) cm from the sources; figure 3 represents results of the sound pressure \( p \), figure 4 of the particle velocity component \( v_z \). Comparing figures 1 and 2 with each other, (and figures 3 and 4) yields the result that the particle velocity in the z-direction is more structured and more concentrated near the sound than the sound pressure. This makes that measurements of this component of the particle velocity should give more accurate results in NAH, than the measurements of the sound pressure [12].
Figure 3. Normalized cross-correlations and (auto-spectra)\(^{1/2}\) of the sound pressure \(p\) as a function of the scanning coordinate \(x\). The points denoted as (*) and (+) refer to the experiment with two sources on; the points denoted as (o) and (.) to the experiment with one source on. The \(x\)-scan was taken at \(y\approx0.5\) cm.

Figure 4. Normalized cross-correlations and (auto-spectra)\(^{1/2}\) of the particle velocity component \(v_z\) as a function of the scanning coordinate \(x\). The points denoted as (*) and (+) refer to the experiment with two sources on; the points denoted as (o) and (.) to the experiment with one source on. The \(x\)-scan was taken at \(y\approx0.5\) cm.

4 Conclusions

It has been shown that in an experiment with two sound sources, excited by two incoherent signals, the contribution to the total pressure (or particle velocity) of the two signals can be separated. As reference signal for NAH the in-plane particle velocity in a direction perpendicular to the particle velocity from one source can be used. For the two sources, these two directions were found from the vanishing of the cross-correlation between these two particle velocities directions. These results can also be applied to the situation with two or more sources excited by two incoherent signals, say \(s_1(t)\) and \(s_2(t)\), or excited by a combination of \(s_1(t)\) and \(s_2(t)\). At a point \(x_1,y_1\) the particle velocity belonging to the signal \(s_1(t)\) has a well defined direction. In a perpendicular direction the contribution from \(s_1(t)\) thus vanishes, and only a contribution of \(s_2(t)\) remains. These two directions \(\alpha_1\) and \(\alpha_2\) can be found from the vanishing value of their cross-correlation. A similar reasoning can be applied for the signal \(s_2(t)\).

When one expects that not two incoherent signals, but only one is present, the above described method can be used as a check for this.

Using the three components of the particle velocity vector it should be possible to separate three incoherent sources. When even more than three incoherent sources are present an extension/combination of this paper with the papers referred as \([5..10]\) seems to be a good opportunity to separate the different sources.

A full paper will be published in Acta Acustica [13].

Acknowledgement.

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References


Appendix, Finding v⊥A and v⊥B.

The v⊥A and v⊥B measured signals have the property that the cross correlation vanishes, since the signals are uncorrelated. Denote the cross correlation between two in-plane velocity components v(αi) and v(αj) as CC v(αi).v(αj). Define α1 as the direction corresponding to the direction of v⊥A, and α2 to the direction of v⊥B. Then in a point (x1,y1): CCv(α1).v(α2)=0. However, in that point x1,y1 there will be many directions where CC v(αi).v(αj)=0, and α1 and α2 are therefore not unique solutions. In the cross-correlation v(αi).v(αj), the contribution of vA or vB in the direction α can be positive or negative and vice versa for αj. In the cross-correlation thus positive and negative terms occurs, which can cancel each other. Consider now two points (x1,y1) and (x2,y2), where in the (x2,y2) point the directions β1 and β2 correspond to the directions of v⊥A and v⊥B. Then considering points (x1,y1) and (x2,y2) separately there are no unique solutions for v⊥A and v⊥B, but combining the two points there are two extra equations, being that the two cross correlations CC v(α1).v(β2) and CC v(α2).v(β1) will also vanish. Thus there are then four equations CC =0 with four unknown variables α1, α2, β1 and β2, which results in most cases in unique solutions. There are even two extra equations: CC v(α1).v(β1)=1 and CC v(α2).v(β2)=1 (the cross correlations should be normalized with the auto-spectra of v(αi) and v(βj)). When taking two coordinate points (x1,y1) and (x2,y2) it is not self-evident that the found solutions indeed correspond to v⊥A and v⊥B, there can be an unwanted (unknown) correlation between the particle velocities in these points. Therefore as extra check more points (three in our study) have been considered, and all the cross-correlations have been calculated. These three points have been taken in the region x=4 cm and 0.5<y<5.5 cm. The solutions for the angles are given in Table 1. The 21 normalized cross-correlations have been calculated for the obtained 3 solutions for which it was assumed that they correspond to v⊥A and v⊥B. Table 2 shows that indeed the 9 CC v⊥A, v⊥B are quite small and the 6 CC v∥A.v⊥A or CC v∥B. v⊥B are close to one; the 6 CC v⊥A.v⊥A the same direction are by definition equal to 1. The results in Table 1 confirm that these directions are indeed the directions of v⊥A and v⊥B.

Table 1. Solutions for the angles (see text).

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<th>y-coordinate, cm</th>
<th>Angle1, degrees</th>
<th>Angle2, degrees</th>
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<tr>
<td>1.0</td>
<td>β1 = 45</td>
<td>β2 = 138.6</td>
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<tr>
<td>1.5</td>
<td>α1 = 50.6</td>
<td>α2 = 130.9</td>
</tr>
<tr>
<td>2.0</td>
<td>γ1 = 57.9</td>
<td>γ2 = 122.6</td>
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Table 2. ( <0.001 means that the value is between -0.001 and 0.001)

<table>
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<tr>
<th></th>
<th>V(β1)</th>
<th>V(β2)</th>
<th>V(α1)</th>
<th>V(α2)</th>
<th>V(γ1)</th>
<th>V(γ2)</th>
</tr>
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<tbody>
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<td>V(β1)</td>
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<td></td>
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<td>&lt;0.001</td>
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<td>-0.007</td>
</tr>
<tr>
<td>V(β2)</td>
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<td>0.997</td>
<td>0.006</td>
<td>0.998</td>
</tr>
<tr>
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<td>0.9993</td>
<td>-0.007</td>
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<tr>
<td>V(α2)</td>
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<td>&lt;0.001</td>
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