COMBINING ACOUSTIC IMAGING TECHNIQUES TO LOCALIZE AND IDENTIFY SOURCES

Authors:
Filip Deblauwe[1], Bernard Beguet[2], Maxime Robin[2]
[1]LMS Interleuvenlaan 68, B-3001 Leuven, Belgium
[2] MicrodB, 7B Allée Claude Debussy, F-69130 Ecully, France
contact: filip.deblauwe@lmsintl.com

ABSTRACT

This paper deals with recent advances in acoustic experimental methods and especially acoustic imaging. The paper covers two areas of interest to acousticians. In the first part, it is explained how near-field acoustic holography (NAH) can be extended with beamforming in the near-field, focalization. The combination of the two methods is providing now a source localization solution with a good spatial resolution over the complete frequency range without the burden of measuring a large number of points as would be required if only NAH was used.
In the second part of the paper, a method is described that goes one step beyond source localization. It is interesting to locate the noise sources, but from an engineering standpoint it is even more interesting to know the internal sources/forces causing these noise sources. In this part is explained how source localization techniques in conjunction with artificial excitation of the structure can provide information on the internal sources of the structure.

1 INTRODUCTION

In the last decennia, sound/noise levels have become more and more important. From on site, governmental regulations are imposed to contain noise pollution while on the other hand customers do not accept a noisy product any longer. On top of all this, the competitive pressure to bring products faster to market, has made that sound engineers are desperately looking for tools giving them an insight on where the noise is coming from. In the first part of the paper, NAH together with focalization is presented as a powerful tool to localize the different noise sources. In the second part of the paper, a method is presented on how these noise source locations can be linked to actual sources.

2 EXTENDING THE USABILITY OF NAH WITH FOCALIZATION.

Nearfield acoustic holography, NAH, is a technique that has been developed in the 90's and for which the formulation is now well known [1-3].
NAH has following major advantages.

- The spatial resolution is equal to the microphone spacing in the hologram and is independent of the frequency.
- Secondly, there is a Dirichlet Green function which allows propagating the measured pressure field to a velocity field. This implies that with this method intensity can be calculated and therefore also the sound power of different zones/components.

This makes the NAH method the true engineering source localization tool. However, NAH has one major practical disadvantage. The spacing between the microphones is defined by either the desired spatial resolution or the wavelength at the highest frequency one wants to analyze. So an increasing maximum frequency implies closer spaced microphones. So from a practical standpoint, NAH is limited to analyze higher frequencies because of the large amount of data that need to be acquired.

Focalization on the other hand is basically a beamforming technique but for an array measured in the near-field instead of the far-field. The fact that the array is placed in the near-field, makes that the waves impinging on the array are no longer planar but spherical, Figure 1.

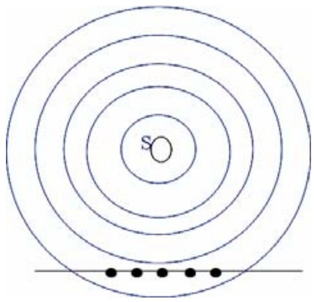

Figure 1: Spherical waves hitting the near-field array

This implies that the classical beamfroming propagation, which is derived for planar waves, is no longer applicable. A phase correction has to be applied which is function of the radius of the wave, Equation (5), rather than the propagation distance. Since focalization is basically a beamforming technique, focalization can propagate to any kind of surface and can handle any kind of array layout.

$$S(f) \approx \sum_{j=1}^{N} P_j(f) e^{ikR_j} \text{ with } kRj = 2\Pi f \tau_j \quad (1)$$

The spatial resolution is still linked to the wavelength but since the data is taken in the near-field, the obtained spatial resolution is 0.44 λ, where as for beamforming the spatial resolution

is (d λ)/D, where d is the distance between source and antenna and D is the size of the antenna. An example of this improved spatial resolution is shown in Figure 2.
Secondly, with the measured plane closer to the source, most energy emitted by the source passes through the array, which is not the case for beamforming. In order to calculate the sound power on a source, the intensity can be calculated based upon the pressure gradient. The integral of the intensity over the surface gives the sound power over the measured surface. Since focalization is a relative method, as is beamforming, these sound power calculations have to be calibrated once. For this calibration a known noise source is used to estimate this calibration factor. This procedure has been done at MicrodB and integrated in the software. Figure 3 is showing an evaluation of the sound power calculation estimates using focalization versus a known noise source

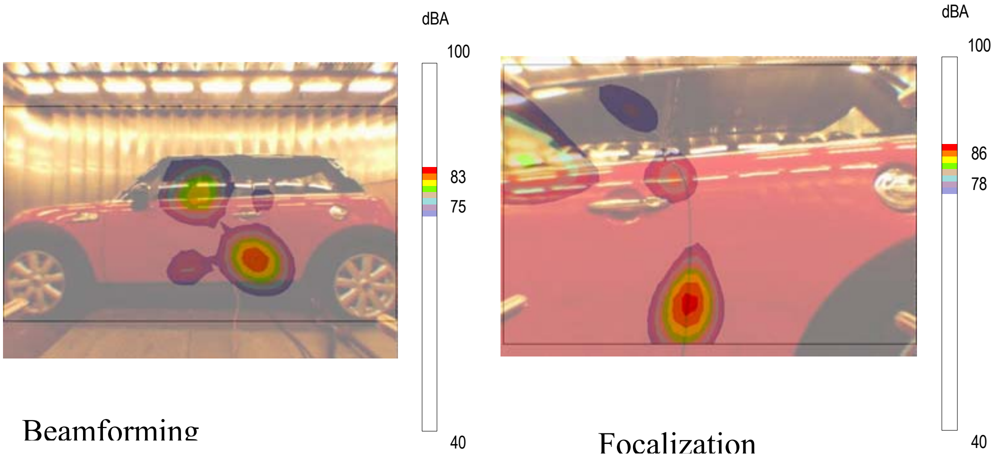

Figure 2: Spatial resolution of beamforming versus focalization

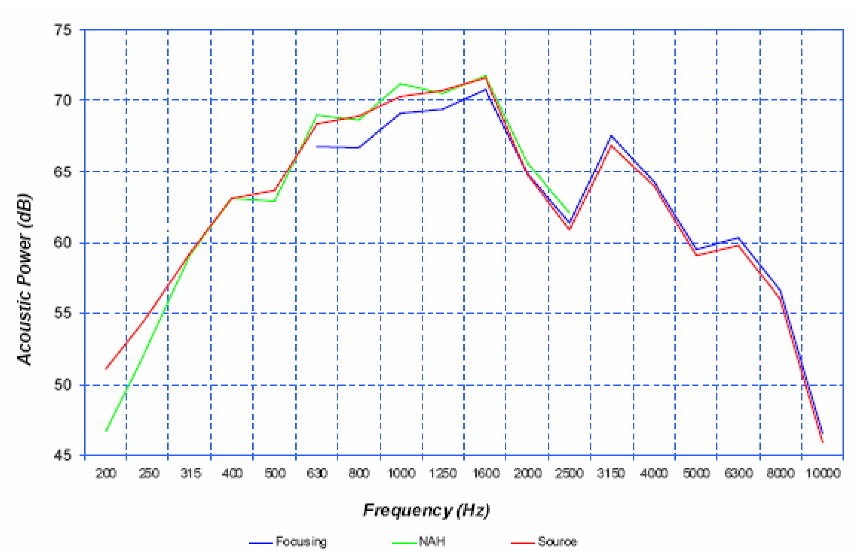

Figure 3: Sound Power calculations using NAH and Focalization

As mentioned before NAH method is limited in upper frequency due to practical acquisition reasons. Focalization can take data from any surface and any layout as input data. So the NAH data, which is equidistance measured, can be processed by focalization. Secondly, at the maximum frequency for NAH the spatial resolution is equal to the microphone spacing which is normally ½ λ. At this frequency, the spatial resolution of focalization is equal to 0.44 λ. So the data that has been acquired for NAH can be processed by focalization at the higher frequencies with a spatial resolution smaller than the microphone spacing. Therefore by using focalization on the same data, the frequency range one can analyze has been doubled. This is shown in Figure 4**Fehler! Verweisquelle konnte nicht gefunden werden.**.

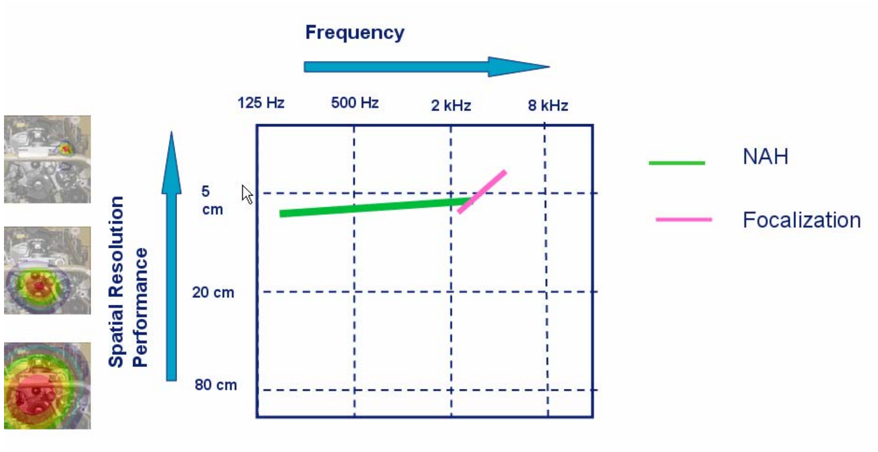

Figure 4: Spatial resolution of NAH + Focalization as a function of frequency

3 LINKING THE NOISE SOURCE TO AN ACTUAL SOURCE

The imaging techniques presented in the previous paragraph allows localizing noise sources on the surface of a structure. This is a first step in resolving a noise source problem. However being able to link these noise sources to internal force/sources, is for a designer an even more valuable piece of information. In this paragraph a method is presented on how one can link a propagated pressure map to an internal source and how these sources can be ranked.

For every structure there is a relationship between the response of the structure and the excitation forces

$$[\mathrm{Re}\,sp]=[H]\{F\} \quad (1)$$

Where [Resp] is the response and {F} is the force. If the responses are measured in operating conditions and the transfer matrix between these responses and a number of force/source locations have been determined, the forces/sources in operating conditions can be determined by:

$$\{F\}_{operation}=[H]^{-1}[\mathrm{Re}\,sp]_{operatoin} \quad 2$$

For this application, two transfer matrices [H] were measured under artifical excitation:

- [H1] transfer matrix between the propagated pressure and the artificial excitation
- [H2] transfer matrix between the microphone array and the artificial excitation

These two transfer matrices allow to first of all calculating the forces in operation:

$$\{F\}_{operation} = [H1]^{-1} \left[\Pr ess_{propragated}\right]_{operatoin} \qquad 3$$

Secondly, once the operating forces are identified, their pressure contribution to the measured pressure can be calculated as follow:

$$\{F_{contribution}\} = [H2]\{F\}_{operation} = [H2][H1]^{-1}\{\Pr ess_{propagated}\}_{operation} \qquad 4$$

This method was used to find the different source contributors in a vacuum cleaner. On this vacuum cleaner all leaks were sealed so that with the source localization the actual sources would be better localized and not the leaks.

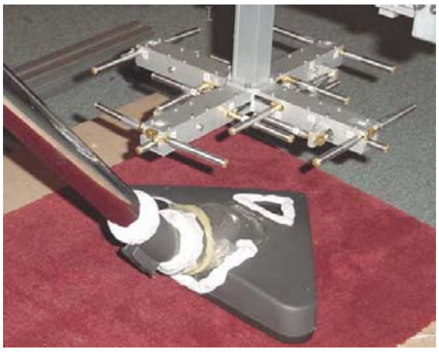

Figure 5: Test set-up of vacuum cleaner

Four potential sources/forces were considered, at the point, at the border, at the corner and at the articulation, see Figure 6. At these different locations a volume velocity source with diameter of 6 mm was used to acoustically excite the structure with a known power level and estimate the FRF matrices H1 and H2.

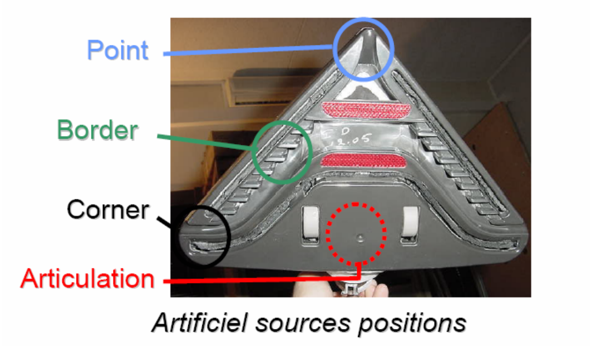

Figure 6: considered potential souces on the vacumm cleaner

Figure 7 is showing the results of these measurement campaign and analysis. In the top part the propagated pressure maps at 1000 Hz and 3150 Hz are shown. Such a propagated pressure map was calculated for each frequency. From this information the operating power sources were calculated at the point, border, corner and articulation using Equation 3. These identified power sources were than used to calculate their contribution at the measured hologram plane using equation 4. The sources contributions on the antenna are shown in the bottom graph in octave format. From this graph it can be concluded that the articulation is the main contributor below 1000 Hz, the border between 1000 Hz and 2000 Hz and the point above 2000 Hz.

4 CONCLUSIONS

In this paper it has been shown how NAH can be extended with focalization and so become a source localzation technique, with a high spatial resolution, that can also be used for high frequencies without the heavy acquisition requirement.

This method has than be used to localize the noise sources on a vacuum cleaner and a method has been presented on how this information can than be used to link these images to an actual force/source. This information is essential if one wants to tackle the tru cause of the noise problem.

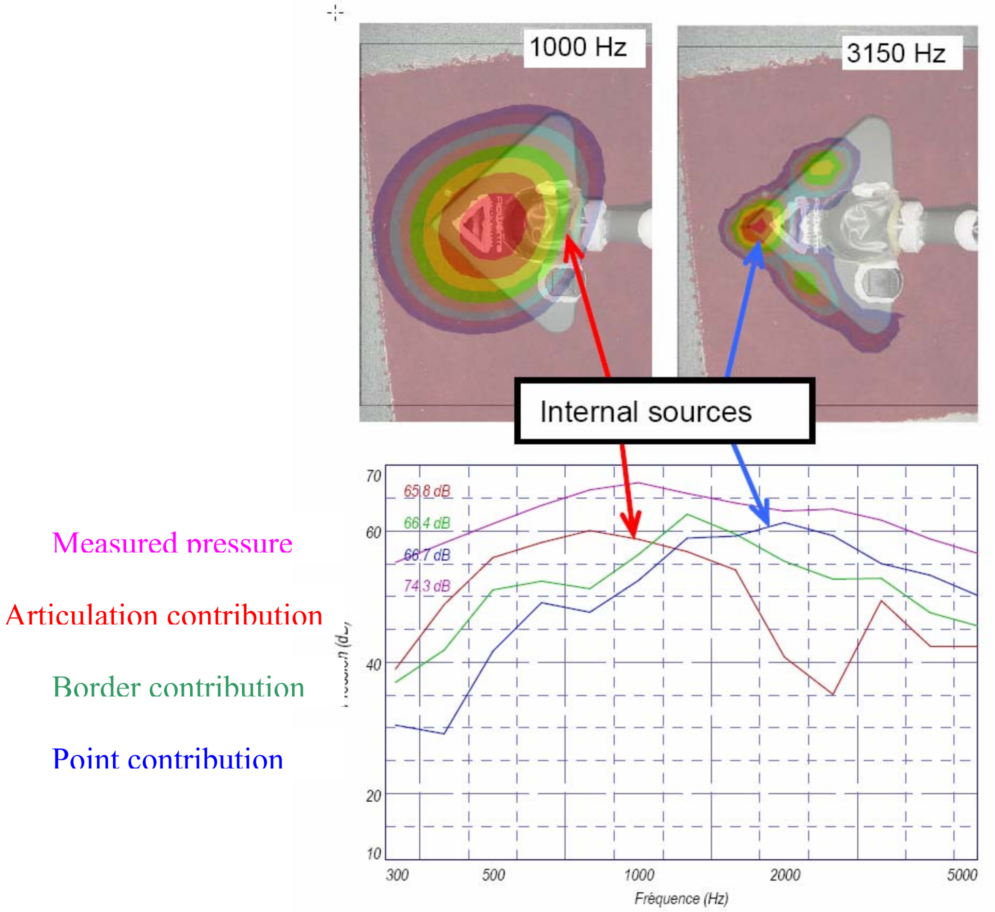

Figure 7: Propagated sound pressure field and contribution of the different sources at the meaured pressure plane

5 REFERENCES

1. J.D. Maynard, E.G. Williams, *Nearfield acoustic holography: theory of the generalized*

holography and the development of NAH, JASA 78(4) October 1985 (1985).
2. J.L. Chauray, B. Béguet, J. Leuridan*, Localisation system for acoustic sources*, euro.noise ‘95*,* Vol.3, pp.927-932 (1995).
3. Bernard Béguet, Jean-Louis Chauray, Filip Deblauwe*, Practical aspects for Acoustical Holography*, inter.noise ‘97*,* Vol.3, pp.1301-1306 (1997).
4. Filip Deblauwe, Karl Janssens, Maxime Robin, *Exteinding te usability of near-field acoustic holography and beamforming by using focalization* ICSV14, Carins Australia 2007
5. Bernard Beguet, Maxime Robin, *Combining acoustic Imaging and identification techniques to localise and identify sources ,* Automobile Comfort Conference, Le Mans France 15-16 November 2006