Full 3D Sound source localization applied on Renault's electrical motor.

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Introduction

The AVELEC project aims to get familiar with new acoustic challenges coming with new electrical vehicles. On such complex systems, it is always difficult to get a complete overview of the acoustic issues. Some widely diffused tools for troubleshooting and sound quantification are the acoustical arrays. They are based on beamforming or holography. Analysis based on such systems are often done on 2D drawing giving the picture, and associated colormap for detection of hot points. It results in one colormap per face and presents some big loss in potential interpretation of sound source location. The low quality of localization usually needs the user to confirm the results by using a time consuming masking method.

Considering the entire array positions around the engine, it is possible to use all the microphones on which signal has been sequentially recorded. Applying synchronization over all microphones allows considering all array position like a single run. Then using the real mesh for back propagation processing finally gives a better estimation for the pressure calculated at the real source location. It results in a really comfortable way to identify the noisy components.

Measurement principle

Measurement system description

An HDCam54 array, produced by MicrodB, has been used. This array is composed of 54 microphones, and is designed for sound source localization up to 10 KHz with a dynamic of 6dB. Its small aperture (50cm) allows setting it in the near field of each engine's face.

To use globally the different positions of the array as a single synchronized one, the first step is to find a way to know spatial position of each microphone relative to the calculation mesh. In its engine test cell, Renault has a 6 axis robot which gives position of its tip anywhere in the bench. It is then used as probe, and for each position, 4 microphones of the array are localized, the same process is applied on the mesh, and for points that are sensed on the real engine. A simple axis system transformation matrix is calculated for spatial positioning.

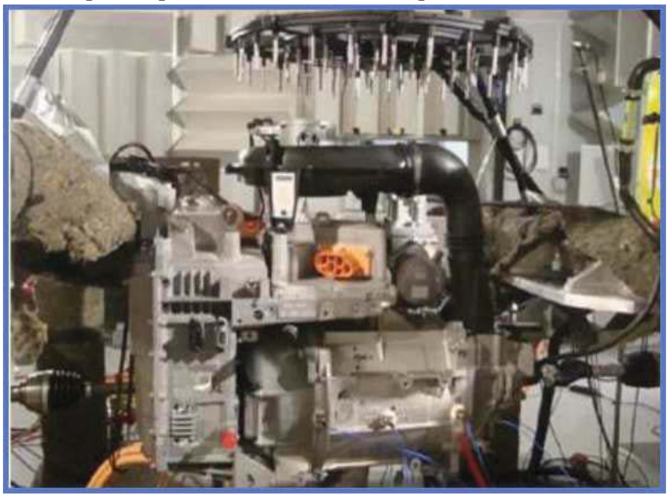

Figure 1. Acoustic array on top face of the engine

Array is successively positioned in front of the 6 engine's faces, and a reference microphone (1 meter over the engine) will be used as phase reference.

At the end, all the microphones positions are known. Picture 2 shows a view of the mesh and the different array location.

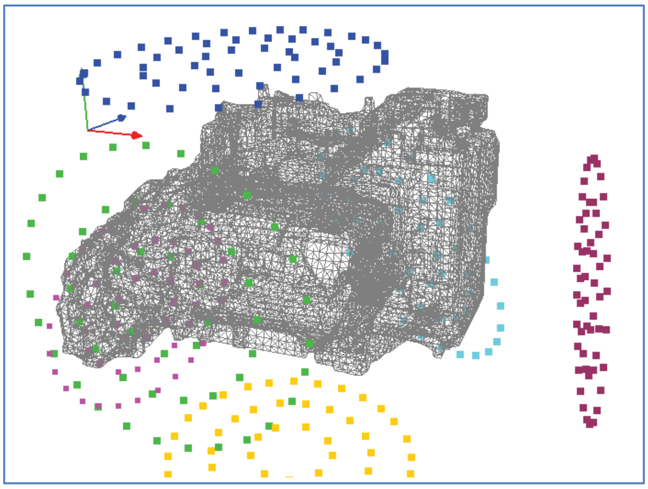

Figure 2. Position of each array after measurement over the 6 faces

Synchronisation and processing algorithm

After positioning is done, the phase reference microphone will be used to synchronize measurements.

To be synchronized, each microphone is processed with coherence calculation based on the reference.

The result is then a database containing synchronized measurements, equivalent to a simultaneously measured signal of all the microphones. Due to practical aspects, this approach is done only on stabilized engine speed.

After that, a visibility matrix is computed for each calculation point from the mesh. A microphone will be "available" if it has a direct visibility on the calculation point.

The final processing is then based on the well-known frequency domain beamforming.

Application on Renault's GEN3 engine

The acoustic signature of the electrical motor in run-up condition is composed of harmonics of the rotational speed; their amplitude is modulated by body behavior at specific frequency/speed. The 10 000 RPM rotational speed is chosen because it contains interesting phenomenon.

Picture 3 shows the result for simulation and array processing at 667 Hz, and 10 000 RPM. The source is localized in the inter-space between control system, and motor itself. This result has been also verified and confirmed with ODS.

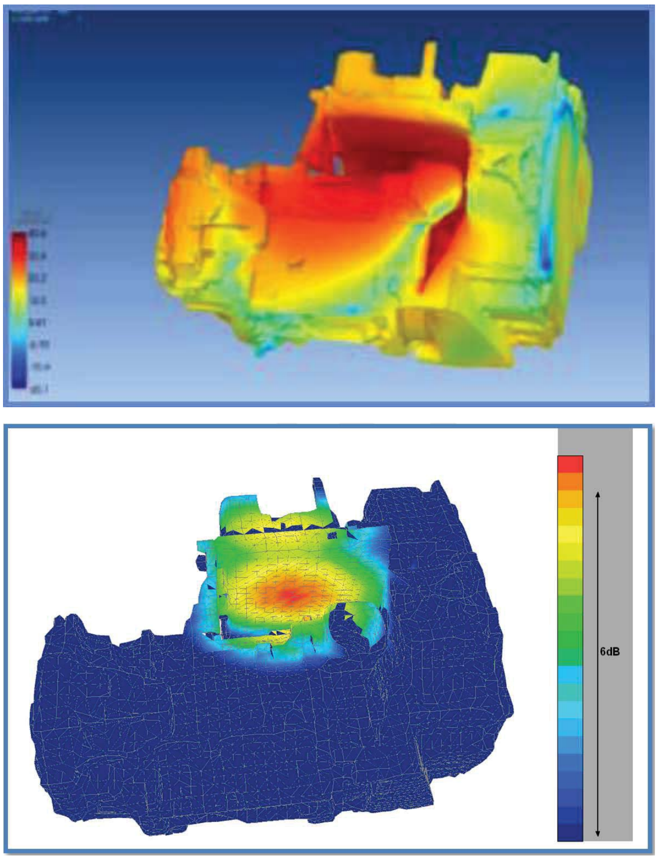

Figure 3. Pressure map at 667Hz, from array measurement on top, and simulation on bottom.

This analysis has been conducted and compared with simulation for all interesting frequency / speed couple, and then a strong coherence between array, ODS, and simulation for all that results is revealed. Furthermore, due to the display quality of the results, source is localized with enough accuracy to avoid masking counter-measure to confirm every result, it allows saving time in measurement, and also possessing.

The picture 4 shows the result for 470 Hz, at 6700 RPM. The two top pictures are from 2D processing, and the bottom one, from 3D processing and display. By comparing the two kinds of processing, results appears equivalent in term of localization, but 3D processing is really easier to interpret. And in addition, the fact that several positions are used for 3D processing build an equivalent array with a higher aperture, and then present some better resolutions at all frequencies.

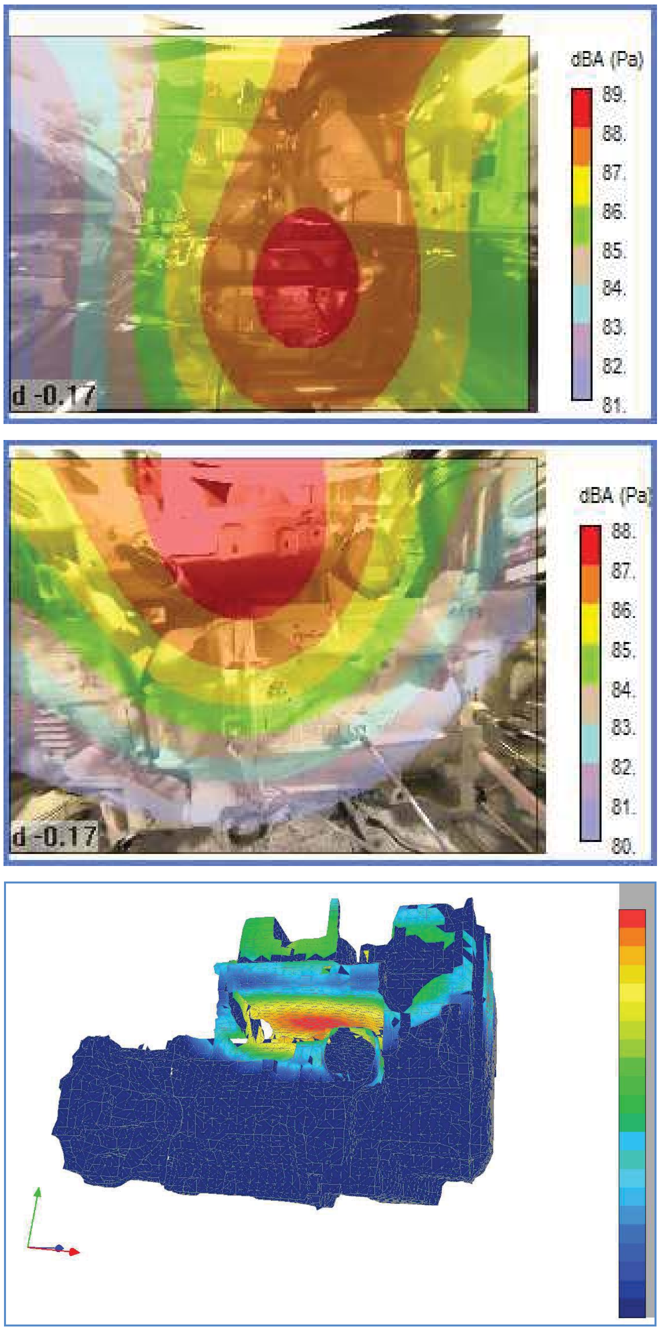

Figure 4. Comparison of holograms at 6700 RPM, 470Hz (2D processing, front side on top, 2D on firewall side at middle, and 3D synchronized at bottom)

Conclusion

Developing and applying this method results in a great improvement in the resolution, and display quality of the pressure maps. It would be nice to consider transfer function also for "un-visible" microphone by using the Helmoltz Integral Equation. To make this approach available in industrial development process the positioning system is not mobile, so a more industrial and portable positioning system must be developed.