Case study

Using simulation to optimize Transfer Path Analysis set-up

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To accomplish the vibro-acoustic evaluation of the model, researchers chose MSC Software portfolio solutions MSC Apex, MSC Nastran and Actran.

About HEAD acoustics

Founded in 1986 by Prof. Dr. Klaus Genuit, HEAD acoustics offers a broad portfolio of products and services covering almost any application in the areas of sound design for technical products and the enhancement of speech and audio quality in the telecommunications industry. HEAD acoustics GmbH is one of the world’s leading companies for integrated acoustics solutions as well as sound and vibration analysis. The products and solutions offered by HEAD acoustics are mainly used in the automotive and telecommunications industry, but also by manufacturers of IT, office, and household appliances, as well as companies and institutions working in the area of acoustic environment protection.

Along with its own research and development work, the company is also involved in national and international research projects and cooperates with universities and other scientific institutions. Numerous patents, Ph.D. theses, diploma and master’s theses, as well as various scientific publications, demonstrate their success in research.

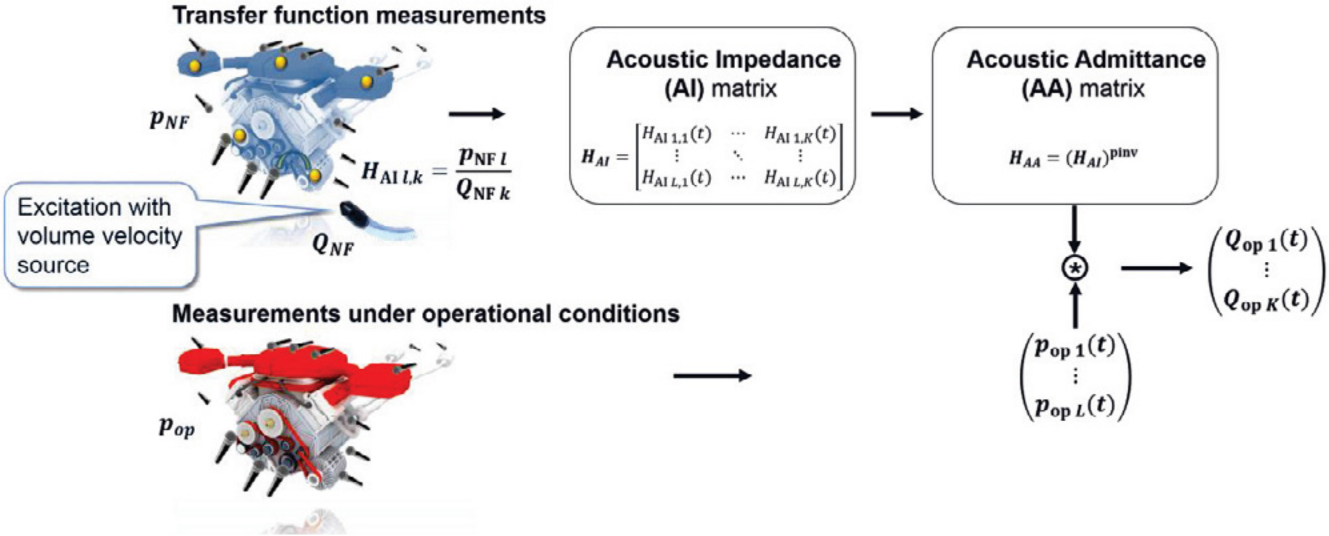

Figure 1 - Description of the application of the matrix inversion method for the airborne case

Challenge

In the past years, noise reduction has become a major aspect to consider during product development, to comply with governmental regulations, enhance environmental comfort and improve user experiences. Noise propagation can be addressed at different levels, namely at the sound source, in the emission process and near sound receivers.

The precise characterization of sound sources is critical, as the major challenge for manufacturers is to identify the main contributors to the sound emission.

In the world of mechanical equipment, if the vibrations of a flat structure cause sound emission, the main contributors (sound source components) are spread over the structure and their quantity and positions vary with frequency, complicating their localization. Several techniques, such as beamforming or intensity measurements, can be used to determine these contributors; however, they do not provide a quantitative characteristic of the source itself, independently of its surroundings.

To answer this question, researchers from HEAD acoustics developed a new methodology based on the traditional Transfer Path Analysis (TPA) and related Matrix Inversion Method (MIM). This new method allows characterizing the source components in a wide frequency range and requires only customary limited sound field measurements.

Optimizing a classic methodology

In classical MIM (Figure 1 - Description of the application of the matrix inversion method for the airborne case), radiating objects are represented by a number of simple acoustic sources such as monopoles. Thus, the problem resolves itself into quantifying these sources (e.g., finding their volume velocity Q). The calculation is based on measured sound pressure in the near field of the radiating structure, and measured transfer functions (acoustic impedance) from the locations of the assumed monopoles to the measurement points (microphones).

A vibrating structure can be decomposed into a subset of parts, each contributing to the final emitted sound. Since the positions and number of the contributors varies with frequency, a meaningful approach to find them all would be to represent the source by a large set of monopoles. Thus at lower frequencies, where the number of contributing components is typically lower, the monopoles that are not present in the source will have low amplitudes and can be excluded in post-processing. On the other hand, at high frequencies, more complex vibration patterns represented by a large number of components will be “caught”. However, a large number of monopoles can lead to numerical issues, as the built-up numerical matrix of transfer functions can be ill-conditioned.

Therefore, the challenge for engineers is the determination of the required monopoles and microphone locations that are relevant for each specific frequency. To answer and validate their proposed methodology, HEAD acoustics NVH researchers set-up a numerical chain to observe the evolution of the matrix condition number as a function of the frequency and number of monopole (i.e., distance between them). Having obtained this dependency, an optimum number for each frequency can be obtained and used.

The numerical investigations were conducted on a representative asymmetric vibrating plate clamped on two sides (Figure 2 - Model of the plate. Excitation point is marked by the arrow.). The dimensions and material of the plate correspond to a typical engine gearbox cover. The asymmetrical characteristics as well as the clamping conditions ensure that the plate itself mostly dominates the airborne noise and exhibits different levels of non-symmetric source patterns.

To accomplish the vibro-acoustic evaluation of the model, researchers chose MSC Software portfolio solutions MSC Apex, MSC Nastran and Actran. “The MSC Apex’s import capabilities and its simple to use defeaturing, modification and meshing tools makes its adoption very comfortable. We used MSC Nastran for its trusted and fast structural FE solver and Actran for its seamless link with MSC Nastran and its dedicated acoustic capabilities such as its solver-based meshing approach and single precision solver for acoustic radiation”, states Serafima Anisovich, Research NVH Engineer at HEAD acoustics.

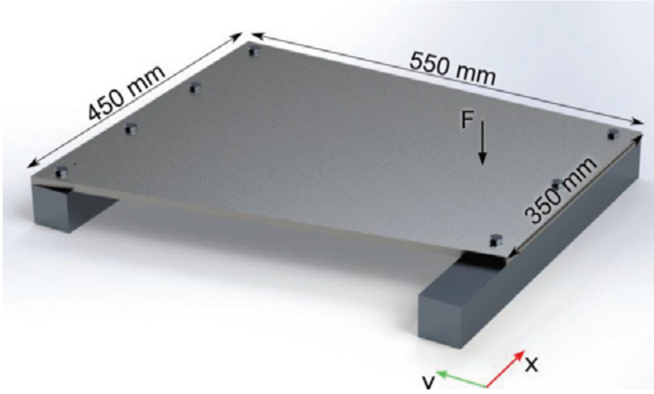

Figure 2 - Model of the plate. Excitation point is marked by the arrow.

Predict structure-borne acoustic sources

At first, the investigations were focusing on validating the ability of acoustic sources to represent structure-borne noise. In Figure 3 and Figure 4, patterns of the structure-borne normal velocity and of the sound pressure at low and mid frequencies are displayed. Both quantities show a very similar pattern. The areas of the plate involved in the movement at most can be considered as the main contributors to the sound radiation.

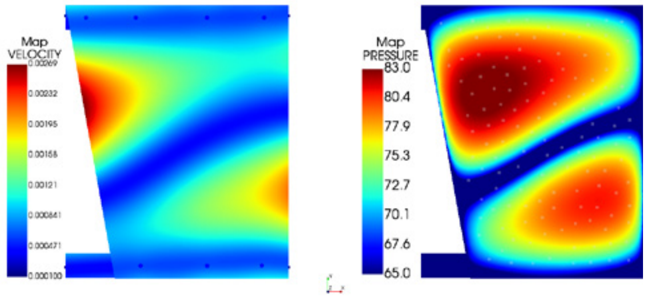

Figure 3 - Left: Velocity map, Right: Sound pressure map on the plate at 260 Hz

Finding the good balance

In a second effort, different monopoles grids, such as regular and randomly distributed, were changed to study the impact on the acoustic impedance matrix. To do so, Actran Python scripting capabilities were used to parametrically change locations of microphones and acoustic sources.

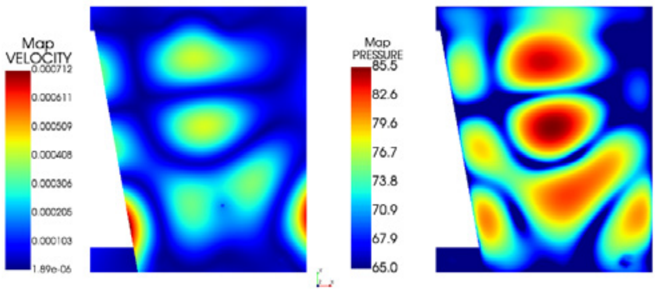

Figure 4 - Left: Velocity map, Right: Sound pressure map on the plate at 1650 Hz

The random distribution of monopoles over of the plate was chosen and microphones were placed above them at a distance r_{ms} = 5 cm (Figure 5).

To find the best model for each frequency, the number of monopoles was changed by simply picking from the full set only the monopoles at a specific distance. The evolution of the matrix condition number as a function of the source distance and the frequency is presented in Figure 6.

A larger number of monopoles leads to an increase of matrix condition number (yellow area on the graph in Figure 6), while exclusion of some points for decreasing the condition number can lead to loss of result resolution. A compromise between these two aspects corresponds to the green and light blue areas on the graph.

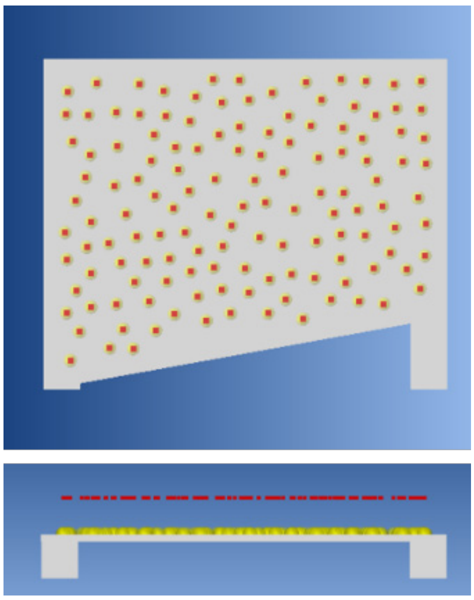
Figure 5 - Setup for simulated measurements: yellow dots – point sources, red dots – microphones

The HEAD acoustics research team suggested treating the ill-conditioned matrix by selecting only matrix elements related to the estimated optimum distance between the monopoles. The found interpolated volume velocity patterns corresponding to different set-ups are shown at the sides of Figure 6. The results of using the optimum set-ups (upper patterns on the right and left sides) match well the expected patterns shown in Figure 3 and Figure 4.

The optimum set-up can be reached by not only picking the monopoles from the full set but also for example by dividing the surface into slots as shown in Figure 7. One slot is then considered as a one-source component. The transfer functions corresponding to the monopoles placed in one slot are averaged. The centre of each slot is then taken as a position of the joint source. The resulting pattern shown on the right side in Figure 7 matches the expected source distribution as well.

Matthias Wegerhoff comments, “The presented simulation chain is used for algorithm development, but can be used as well for product development. For obtaining more flexibility to enable the virtual prototype during development process, the combination of experimental and numerical investigation is also promising. For example, sources representing blocked forces can be implemented into simulation. Anyone who wants to accelerate the development process for algorithms or hardware products can rely on the outcome of this study.” Serafima Anisovich adds, “Based on this research we could build up a full chain of simulation that can be used for auralization purposes as well. The obtained auralized results were validated against measurements and were found to be reliable.”

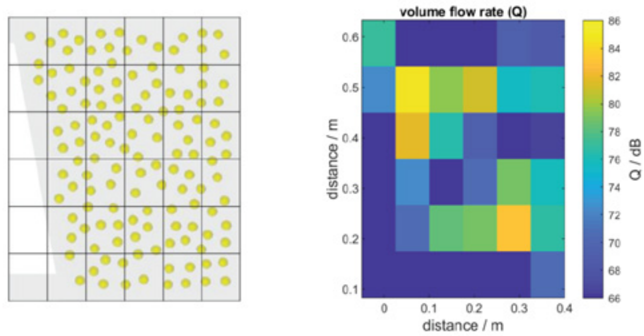

Figure 7 - Left: Illustration of the separation of the model into 32 spots and grouping of the initial Qsource, Right: Resulting volume velocity for the modified model (for 260 Hz)

Moving forward

The implemented tool chain can be fed with sources representing blocked forces. It becomes therefore a methodology able to tackle situations with sources like pumps or electrical machines. It is of particular interest for OEMs willing to integrate components into their system for which they do not have constructive details.

The acquired component will be measured in-situ and the resulting measured blocked forces can be transferred into simulation.

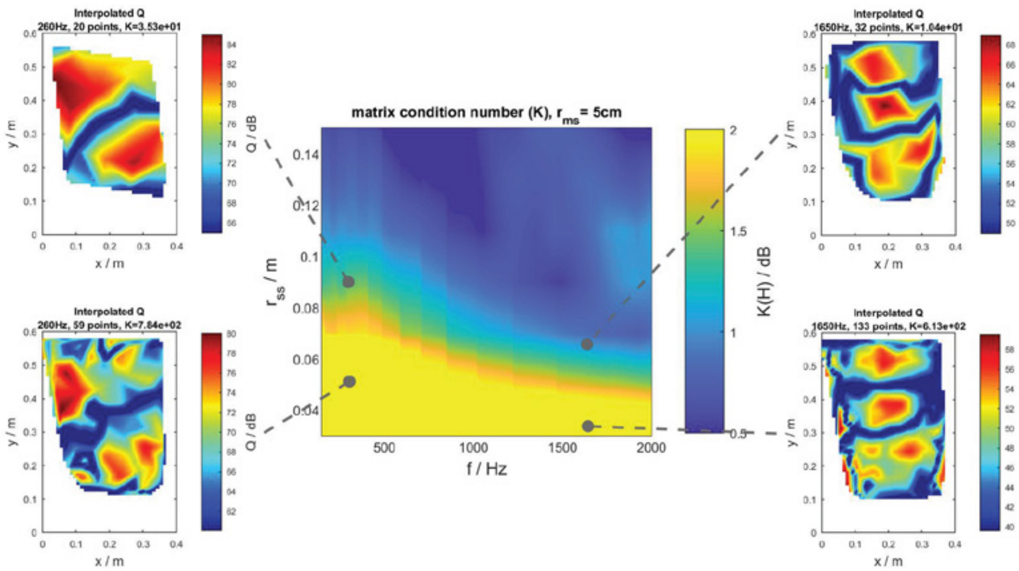

Figure 6 - Mid: Matrix condition number depending on frequency and distance between the assumed sources.
At the margin: Examples of interpolated volume velocity patterns for different measurement setups at particular frequencies

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