Meeting Noise Regulations with Nearfield Acoustic Holography

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Current and upcoming noise regulations in Europe and throughout the world are forcing machinery manufacturers to improve the Noise, Vibration and Harshness (NVH) characteristics of their current products. Furthermore, these new regulations must be fully considered in the design of new products. Fortunately, newer measurement techniques such as Nearfield Acoustic Holography (NAH) can ease the burden of NVH testing and design. This article gives a brief explanation of some noise requirements, provides a short background on NAH and considers its application in one example.

The European Economic Union (EEC) is setting up many directives and regulations on machinery noise. The 2000/14/CE directive sets constraints on the external noise radiated by machinery of all kinds. The 89/391/CE and 88/166/CE are respectively focused on the vibration and noise to which operators are exposed. Safety directive 95/37/EEC calls for all machinery manufacturers to achieve safe sound levels inside and outside the machine using state of the art measurement and testing techniques.

These noise regulations are not limited to Europe. In Japan, the Ministry of Construction has issued stringent noise regulations for machinery, while Australia is currently preparing noise regulations of its own. In the United States, OSHA (Occupational Safety and Health Administration) and MSHA (Mine Safety and Health Administration) are imposing noise restrictions based on standards created by the Society of Automotive Engineers (SAE) for both external noise and operator-subjected noise.

These regulations impose limits on the externally radiated acoustical power as well as the operator sound level (SL). For the operator sound level, EEC regulations indicate that the SL should be under 85 dBA for typical eight hour operations. Between 85 and 90 dBA, individual ear protection *should* be worn, while between 90 and 95 dBA ear protection *must* be worn to operate the machine. Beyond 95 dBA, care must be taken to minimize exposure to and operation of the machinery. SL information can usually be found on the machine's sound declaration plate(s) and/or in the operating manual.

Designing and Testing Machinery

Product engineers must incorporate noise constraints at the design stage. This was not always the case. In the early phases of the noise directive, existing machinery was often modified with soundproofing or layout changes to meet the demands of the regulated markets. With more stringent noise requirements, NVH must now be considered at the design stage. The relationships between machinery design and operating noise can easily be evaluated using state-of-the-art computation techniques. This is a common practice in the automotive industry but is often overlooked by other machinery designers.

The A-weighted sound pressure level has become the standard for noise measurement and modern testing techniques try to improve it by evaluating several different configurations. While the tests provide a clean, one-number result, that result is often obtained through time consuming techniques (intensity, pressure mapping), a fact that is often lost to engineers and technical managers not directly involved in the testing.

Case Study

NVH development adds another cost – and thereby another challenge – to design and manufacturing. For high volume, mass produced machinery, the cost of soundproofing can usually be integrated into the development and production budgets to bring skilled NVH engineers and technicians onto the design teams. However, for specific applications and low volume machinery, the resources and time necessary for NVH development are not always available. One solution to the problem is outsourcing NVH development, a practice that results in strong partnerships between NVH service providers, suppliers and machinery manufacturers.

In the case history presented here, Nicolas Industries, a leader in heavy material handling machines with applications ranging from steel mill logistics to aerospace machinery, contracted Metravib RDS for NVH development.

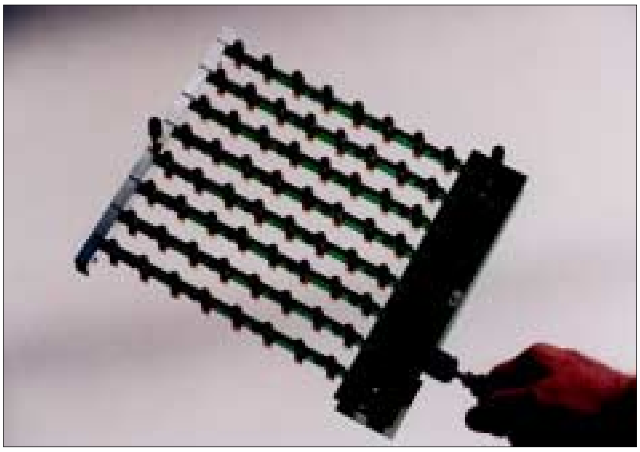

Figure 1. 64-channel microphone array.

Figure 2. Cab mounted on the truck and in the test cell.

Figure 3. Outside view of the six new test cells at Metravib, Limonest, France.

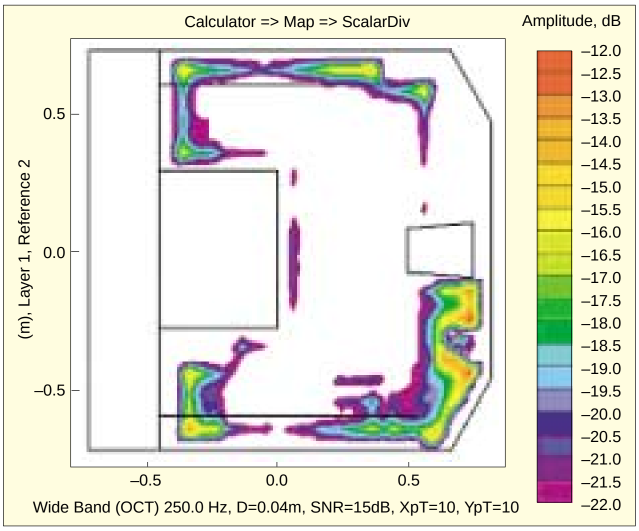

Figure 4. Floor transimission loss at 250 Hz showing direct noise path through air vents and steering pedals.

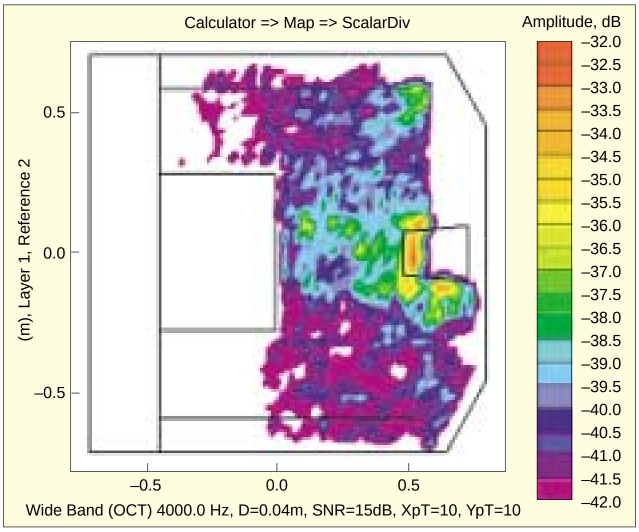

Figure 5. Floor transmission loss at 4 kHz showing leaks around the steering rod.

Holography

Metravib RDS has played a key role in developing the technique of Nearfield Acoustical Holography (NAH). NAH has its roots in naval underwater holography (SONAR) and has evolved into portable tools that can be used in the confines of automotive enclosures.

In a nutshell, holography is used to build farfield sound estimation maps from nearfield measurements. An array of microphones with known spatial positioning (see Figure 1) is used to measure the structure at many locations in the nearfield domain. Phase reference information is simultaneously collected by several microphones placed at particular reference points.

Data analysis requires all positions and orientations of the microphone array to compute the exact position of each pressure transducer. To keep track of the array, it is either moved at the end of a 3D measuring arm or set on a measurement mesh drawn onto the structure. The measurement points are not equally spaced, so a diffuse interpolation algorithm is used to rebuild an even mesh.

In the vicinity of a sound source, the acoustic field is composed of two kinds of waves: propagative (active) waves that are organized and radiate out from the source at sound velocity; and evanescent (reactive) waves that are close to the source, not organized and do not carry acoustic energy farther than a certain distance (known as the Fresnel domain). A good illustration of this phenomenon is a boat sailing on a calm lake – the turbulence next to the disturbance caused by the boat motion illustrates the reactive field (i.e., the reaction of the water to the motion of the boat) as organized sine waves (active/propagative) are running away from the ship.

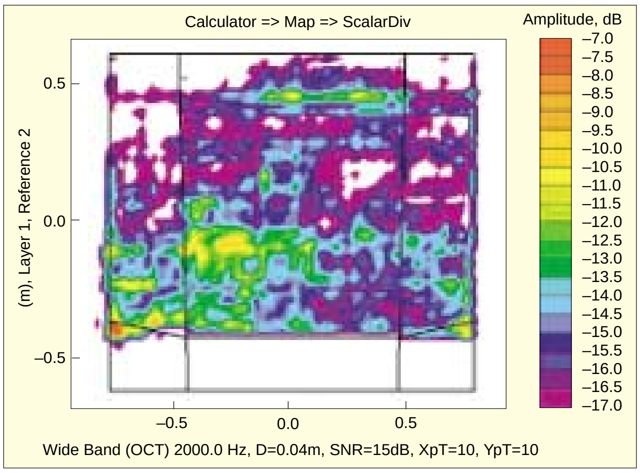

Figure 6. Map of the front windshield transmission loss at 2 kHz. A defect is identified at the lower left corner coming from poor sealing efficiency.

The farfield radiating waves are separated from the evanescent waves (based on a plane waves model) using a spatial Fourier transform – i.e., a decomposition of the acoustical signal into the wavenumber space. Both components are then back propagated onto the structure plane and the maps are built based on eigen component analysis separation of the active and reactive parts of the sound pressure field.

There are frequency limitations on this technique. When working inside a closed volume, the reverberant field will set a limit on low frequencies, although this can be minimized by placing absorbers on all faces besides the one being measured. High frequencies are limited by the spacing between microphones.

Cab Application

Nicolas Industries contacted Metravib RDS recently for a noise issue at an operator station. The operational noise level in the operator cab with engine at full load was high, impeding the correct understanding of radio messages from the control center. A primary diagnosis was performed onsite and clearly identified transmission loss defects in the cab floor, as well as the overall poor acoustical conditions encountered in the cab.

Following the onsite test, the second step was to study the whole cab in a Metravib RDS test cell at Limonest (Lyon, France). A finished cab was obtained from Nicolas and moved to a test cell (Figures 2 and 3) where it was placed over speakers that played recorded signals under the cab. The various gains were adjusted to get an incident field at the same level as the one measured onsite.

Based on the customer's production schedule, the cab was available for a time frame of one week, during which all the exposed testing and analysis took place. Due to the frequency limitations for this particular cab, the analysis was valid over the 250 Hz to 4 kHz octave bands. A 64 channel microphone array was used to measure sound fields over the floor and walls of the cab. After gathering the data, NAH maps were built with Metravib RDS LORHA® software.

The results confirmed hypotheses and measurements from the first onsite study and indicated that a large part of the acoustical energy flowed through many leakage areas, as well as door seals and spot welded sheet metal junctions (Figures 4 and 5). The transmission loss of the various window glazings was also measured in its real configuration and coincidence appears clearly on the plots (Figures 6-8). After this first day of testing, all identified acoustical leaks were sealed, a prerequisite to further acoustical treatments such as barrier and ab-

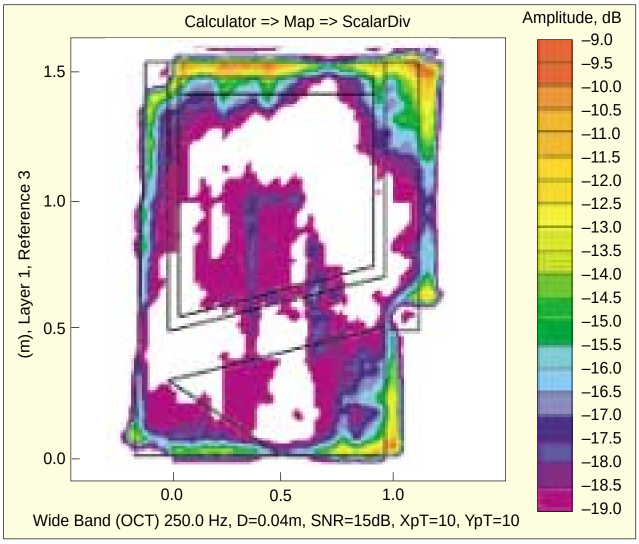

Figure 7. Map of the side door at 250 Hz showing a transmission loss defect along the door seal.

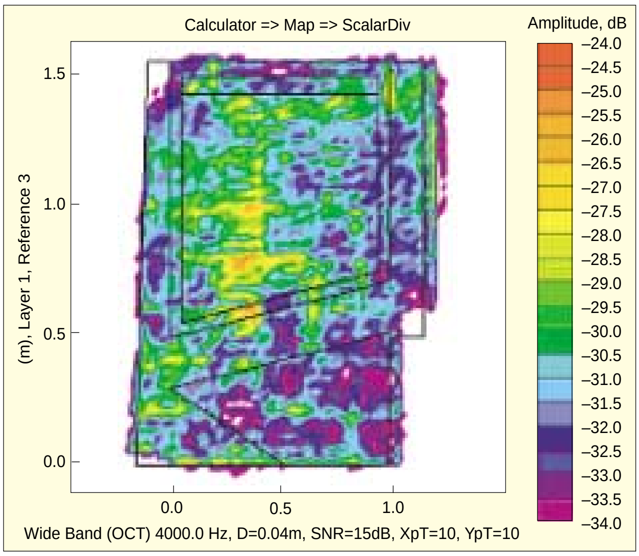

Figure 8. Side door transmission loss close to the glazing coincidence frequency (4 kHz).

sorption improvements.

A mock-up of the 'treated' cab was created using a set of several prototype floor mats and liners. For each modification, measurements were performed at the operator's ear. These led to the building of "sound level reduction vs. floor mat weight" and "sound level reduction vs. Sabine surface" curves, which can quickly be translated into overall cost/dB curves.

Through constant communication with Nicolas, a final design was obtained leading to an SL reduction of over 14 dBA at the operator station. Onsite measurements including structureborne noise (not previously considered) confirmed these results.

Conclusion

Acoustical holography considerably reduced the investigation time in this measurement and allowed direct focus on major noise contributors at the operator's ear. While there are some limitations to NAH (particularly its metrological performance), it definitely constitutes a powerful diagnostic tool for NVH engineers. Furthermore, acoustical holography provides sound level maps of the entire structure. These are easily superimposed over design prints to clearly show troublesome spots. This eases communications between engineers and managers when dealing with machinery NVH problems.

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