BUS ACOUSTIC PERFORMANCES OPTIMIZATION

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Abstract: Invitations to tender from public transport companies have more and more draconian specifications with regard to the inside and outside vehicle noise level in order to satisfy public expectations. These requirements lead the manufacturers to improve the acoustic performance of existing vehicles and take into account the vibroacoustic aspects in the design of new vehicles. This article presents a methodology characterizing and optimizing the vibroacoustic performance and the behaviour of an existing bus. Firstly, in order to determine the areas to upgrade, an acoustic cartography of the vehicle was carried out in the whole of the cockpit and at the outside rear of the bus. This stage was completed by acceleration measurements in these areas and on main vibratory sources. Analysis of this information along with the spectral analysis of acoustic pressure in these areas in low and middle frequencies, has allowed us to characterize the vibroacoustic behaviour of the vehicle. Laboratory insulation and absorption tests were then carried out under representative conditions of bus structures to be upgraded in order to determine the optimal soundproofing solutions. Innovating treatment solutions were developed on the basis of new-generation acoustic materials. These solutions were then prototyped and attached to the vehicle in order to directly verify their effectiveness. A final acoustic cartography of the noisiest areas and the validation tests showed the relevance of the method and of the soundproofing solutions which will be fitted by IVECO on the new generation bus.

1. Introduction

In order to reinforce customer satisfaction and to avoid any harm coming to local residents, public transport companies specify inside and outside acoustic performance criteria to be met by bus manufacturers in their bids for tender. As a result, bus manufacturers and their partners have to intensify their efforts to reduce acoustic pressure levels. The study of new vehicles involves vibro-acoustic issues right from the start design. But since vehicle models tend to have a 15 year life-span, bids are generally made based on existing vehicles, for which the vibro-acoustic behaviour needs to be improved. A characterization and optimization methodology will be presented for an existing bus, AGORA LINE from IRISBUS. The first step was to investigate the sound emission areas inside and outside the vehicle. Then it is possible to identify the areas of vibroacoustic weakness and to characterize their influence on the total acoustic energy levels. The following step was to develop and optimize the soundproofing solutions in laboratory. The best solutions were then prototyped and fitted on the vehicle for validation tests.

2. Detection of Vibroacoustic Weakness Areas

2.1. Methodology

The vibroacoustic optimization of the bus was carried out through the installation of soundproofing materials, rather than by modifying sources or bus structure due to a lack of time. We needed to identify the acoustic weaknesses of interior trim and outside parts of the vehicle.

Before starting characterization tests, a preliminary auditory and visual study of the bus structure was carried out. This was initially to understand how various sound sources could evolve and be propagated. The AGORA Line bus has a longitudinal engine located in the left rear side, coupled with an automatic gearbox. The power is transmitted to the bridge directly by a cardan drive. These noisy parts cover all the left under carter to the rear axle : it is obvious that the coupling, hydraulic, pneumatic and engine noises are the sources to treat in priority

2.2. Test Methods

Various vibroacoustic test methods exist, but the idea was to propose a fast solution while minimizing costs. Concerning vibratory measurements, a traditional technique was chosen using piezo-resistive accelerometers. The fact of being intrusive or not in measurement was not an obstacle. The sensors were easy to install which made it possible to study all parts of the bus without restriction. We chose to use acoustic antenna to locate the areas of vibro-acoustic weakness. We knew that it was not useful to know the acoustic power radiated in the cockpit of the vehicle, but it was necessary to be able to compare the evolution of the acoustic solutions fitted. As a result, we used the free field beamforming array from Müller BBM and its system of acquisition and post treatment. The advantage of this technique lies in the facility of installation, and particularly in the rapid determination of the main sources, in terms of localization and classification by acoustic pressure level cartography on the measured panels. It is also possible to cover relatively important surfaces easily (up to 7m ² for one measurement). The band of analysis chosen for this study was 100 to 2200Hz, but the measurement system could focus on smaller band-width, as we did for some areas.

Figure 1. Acoustic antenna measurement in semi-anechoic-room.

A microphone array in near field was also used on certain external parts of the bus (bridge, exhaust system), in order to be able to quantify and classify the importance of the acoustic power of these parts. This technique uses a smaller antenna : the system developed by MicrodB with its SuividB software under OROS system was used for this study. In semi near field situation, it allows for the calculation of acoustic pressure and an estimation of the acoustic power.

2.3. Different stages

Apart from an essential prototyping stage, two other important experimental stages were the subject of this study. The first stage initially consisted in carrying out the acoustic and vibratory cartography for the complete vehicle, inside and outside. The fitted soundproofing solutions and the seats were removed. With this first step it was possible to note that the first areas of improvement were located at the backside of the vehicle, after the rear axle.

The measured areas, (approximately 5m²), were instrumented simultaneously using accelerometers laid out according to a precise grid.

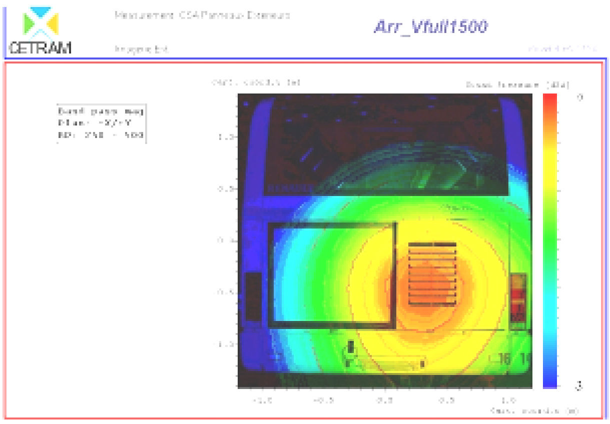

Figure 2. Acoustic cartography computed for band-width 250-500 Hz at 1500 rpm.

The correlation between the vibration and the sound pressure spectrums of the antenna's central microphone, allowed us to differentiate the problems of transparency with those of panel radiation. In complement, the origin of the most influent frequencies in the total sound pressure level could be given with a band-widths focus of the cartographies. Then, we had precisely localized the origin of the noisiest areas. This stage was very important, because it was the starting point from which we needed to choose the right way to reduce vibroacoustic weaknesses.

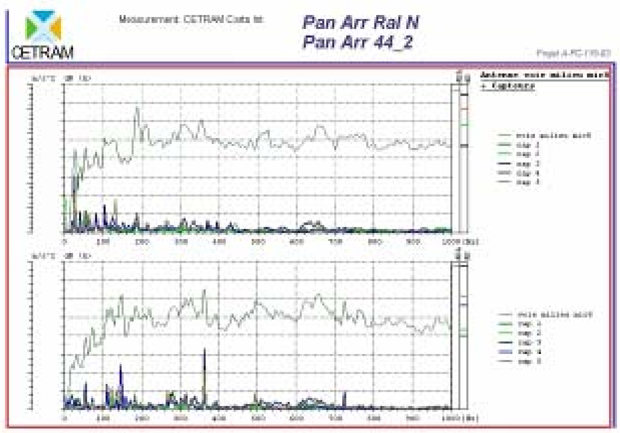

Figure 3. Sound pressure level spectrum of the antenna's central microphone and acceleration spectrum for different measurement points of the back panel.

The sound power measurement of noisiest sources like the bridge and the silencer of exhaust system allowed us to estimate their influence on the total sound pressure level measured inside and outside the bus. All measurements were carried out and analyzed following two types of test drawn up in the customer specifications: at idle and defined rpm, in semi-anechoic room, on standardized test track, and on a road for pass-by noise, inside and outside noise at stabilized rpm. After a meticulous analysis, the areas to be treated were defined (backside cockpit, floor and engine compartment), technical improvements were proposed such as architectural modifications and soundproofing solutions.

3. Development of the optimum Soundproofing Solutions

3.1. Inside the bus

The identified areas of weakness correspond mainly to problems of transparency, notably at the back of the vehicle. They can be classed in three different categories of bus structure:

- The firewall, separating the engine compartment from the cockpit made up of two composite layers with an inside acoustic treatment,
- The floor made up of metal sheet, a space to insert suitable acoustic treatment, wooden panel on the top, and a carpet,
- Another part of the floor, localized at the top of the fuel tank with wood lying on mesh wire, and a carpet.

In order to increase vibroacoustic performance, the three types of structure were prototyped and optimized in a laboratory. A double acoustic box was used to measure the insulation of samples and compare them. Improvement solutions were prototyped for each layer and tested to evaluate their performance. The insulation performance was tested by superimposing the results obtained from the double box, with the measurements of the acoustic pressures from many areas in the engine compartment and under the body. A classification of the solutions in term of insulation performance, once fitted on the vehicle, was simulated using these estimations.

3.2. Engine Compartment

The engine compartment was upgraded by several new treatments. Since acoustic performance improvement of sources such as the engine and the bridge were excluded, corrective soundproofing solutions were developed based on manufacturer specifications.

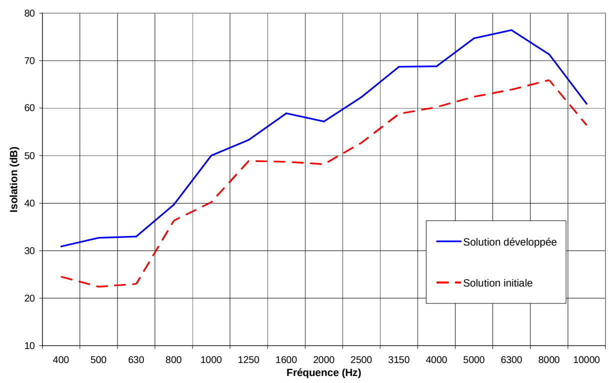

Figure 4. 1/3 Octave insulation Spectrum of the Silent Cushion measured in double box CARPENTER.

- To develop a new waterproof sound absorption system called SILENT CUSHION, in conformity with the customer specifications, notably with regard to waterproofing peeling and tearing.
- To develop and reinforce the soundproofing solutions near the principal sources,
- To modify exhaust system components.

The acoustic performances of SILENT CUSHION were initially characterized on a test bench developed by CARPENTER in order to optimize the spectrum of operation before being assembled on the vehicle for validation.

Figure 5. SILENT CUSHION fitted on backside panel.

4. Validation In Situ

The best laboratory-developed solutions were prototyped and fitted to the vehicle. Prototyping included the backside of the bus which was changed as well as many areas located on the back part of the vehicle, where principal sources were situated. The areas which were initially the noisiest were then evaluated after treatment through an acoustic cartography technique under conditions defined in initial specifications. To facilitate the implementation, after treatment for external noise, the cartographies were measured in static condition. The solutions proposed were prioritized (3 for the cockpit area, 2 for the engine compartment) based on the cartography calculated when comparing the levels obtained.

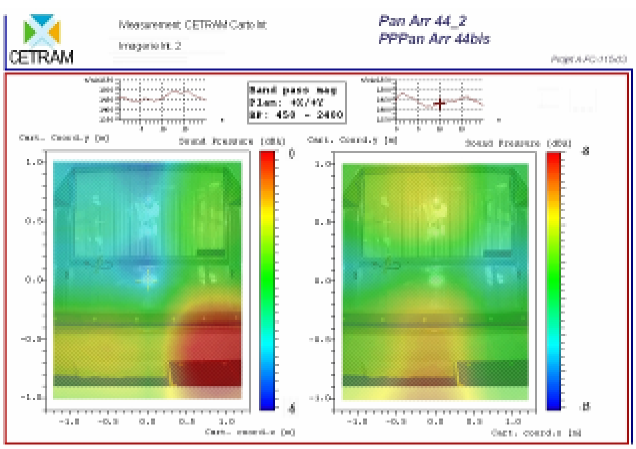

Figure 6. Acoustic cartography of the backside, before and after and after treatment at 1450 rpm.

5. Conclusion

The methodology developed fulfilled the goal for this study. The areas of vibroacoustic weakness inside and outside the bus was identified, their origin and which to treat in priority in order to reduce global noise levels were found. Soundproofing solutions, including innovating concepts, were developed in the laboratory and fitted on the vehicle for validation. Compared to the version tested initially without soundproofing, the global acoustic level pressure was decreased by 3.9 dB (A) for noise at 44 km/h (test method in conformity with the standard ISO 362) and by 7.5 dB (A) for the inside noise at idle in the backside of the vehicle.

References

[1] Möser, M., (1988) : Analyse und Synthese akustischer Spektren (Analysis and Synthesis of Acoustic Spectra), Spinger Verlag.