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Simulation Methodology for Pass-by Noise Optimization

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ABSTRACT: Exterior vehicle noise is increasingly regulated and stricter requirements require optimization at an earlier design phase and attention to component-level target setting. Combining key simulated transfer functions with measured sources from component-level testing can be used for early-phase exterior noise predictions and to complement testing, especially indoor tests, at later stages of design. The effect of trim and sound package on exterior noise can be predicted with this approach. A validation case is presented along with capabilities and limitations of some proposed simulation methods and some recommended next steps for improvement of accuracy and process.

KEY WORDS: **vibration, noise, and ride comfort, acoustic material**, **boundary element method (BEM)**, Pass-by Noise (A1)

1. INTRODUCTION

Regulations, aimed at reducing the Pass By Noise levels of automotive vehicles, challenge the current method of measuring Pass By Noise which deploys a microphone on a test track or a microphone array in a test chamber that results in a simple pass / fail assessment. Pass-by Noise measurement performed on a test track is especially subject to environmental variability which makes test results repeatability challenging. When countermeasures are necessary, on top of having to implement them late in the design cycle, a trial-and-error process is often used. This makes difficult to evaluate if design changes result in an improvement to Pass-by Noise that is within the testing variability and it is hard to confirm via test alone.

More rigorous Pass-by Noise targets resulting in lower noise thresholds from a vehicle accelerating during the test, that now take into account tire contributions, drive a need for time/speed based analysis of all contributing acoustic sources.

In this paper a Pass-by Noise simulation case study on a car and its validation, performed in conjuction with General Motors, is presented.

2. PASS-BY NOISE SIMULATION PROCESS

2.1. Source - path - receiver approach

The Pass-by Noise simulation process used in this study and validation case is based on the “source-path-receiver”[1] approach, a very well known and accepted method by the NVH community, to predict and analyze noise and vibration levels of a complex mechanical system via pure simulation data, pure test data or a combination of both. For this method, it is necessary to quantify sources and paths and combine them in order to predict noise and vibration performances. Path quantification means the calculation or measurement of Frequency Response Functions between sources and receivers. In the present work sources were acquired and analyzed by test; paths were calculated and measured to perform model validation and receivers predicted and measured in order to perform Pass-by Noise levels[2] comparison.

2.2. Paths quantification and validation

In this work it was chosen to calculate and measure Frequency Response Functions for Pass-by Noise prediction and correlate them using a model that matches the indoor Pass-by Noise set-up.

An ESI VA One[3] Boundary Element Model (BEM) of a car (Fig.1) was built including sensors, sources and floor, using infinite rigid plane, in order to reproduce the test set up of the hemi anechoic room.

The model’s mesh is valid up to 2,500 Hz considering six element per wavelength and consists of about 97,000 wetted nodes, resulting in a mesh size of 22 mm.

The BE model contains acoustics sources defined by monopoles that represent the power inputs of Volume Velocity Sources (Q).

The BE model was solved using a DMP solver overnight and computation cluster and 720 P/Q Frequency Response Functions

(FRF) were then calculated between each monopole and each sensor.

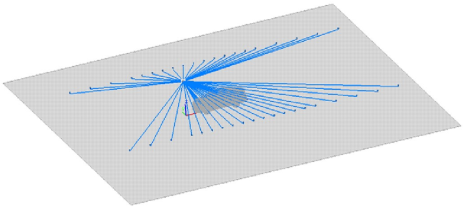

Fig. 1 BE model of indoor Pass-by Noise test set up.

FRF test measurements were performed at General Motors proving ground in a hemi-anechoic room in order to correlate the BE model. Transfer functions were measured between receiver and source locations; Q source was placed at receiver location and microphones were placed at source locations.

Two different kinds of Q sources were used, low-frequency and mid-frequency, in order to correctly cover the full spectrum of interest.

Fig. 2 Transfer functions measurement set up.

Considering the large amount of data to analyze, it was chosen to use sum of selected FRFs for the comparison of test and simulation.

Microphones were grouped considering the closest source locations as shown in Fig. 3.

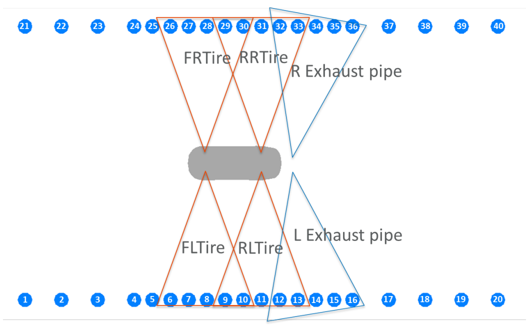

Fig. 3 FRF grouping for test – CAE correlation.

Correlation results were very good for external sources (Fig. 4) but not fully satisfactory in the first attempt for sources around the powertrain (Fig. 5).

Then generic but reasonable impedance values were applied in the simulation model to the hoodliner and the engine cover to take into account noise control treatments.

After model rerun, results for interior sources were significantly improved as shown in Fig. 6.

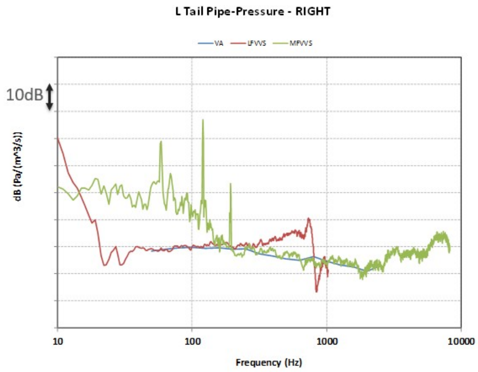

Fig. 4 FRF comparison for exterior source.

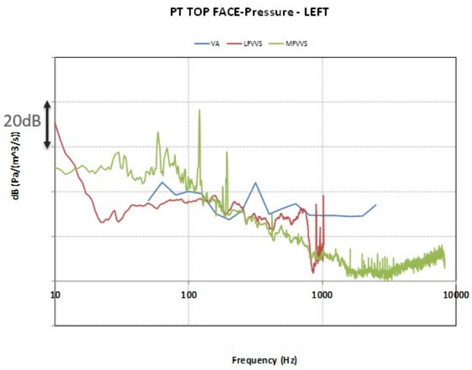

Fig. 5 FRF comparison for interior source no trim applied.

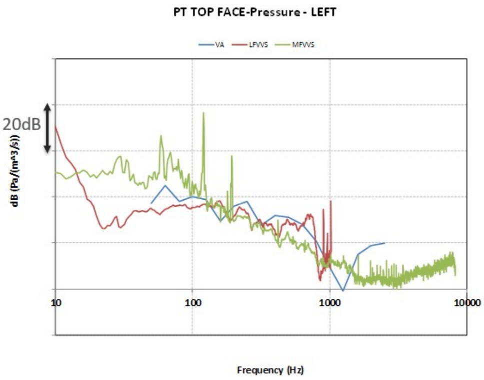

Fig. 6 FRF comparison after model modification for interior source.

2.3. Source quantification

Volume Velocity of the source (or its sound power) must be back calculated from each source in order to be implemented in the BE model. The well known Transfer Path Analysis (TPA) is the chosen method to obtain the Volume Velocity sources. To

quantify each engine source in terms of volume velocity, 18 microphones were placed around the engine compartment at locations where the volume velocity source can be calculated. In a second step transfer functions (p/Q) between microphone and engine sources were measured.
Volume velocity source are obtained with the following formula:

$$\{Q_i\} = [T_{ij}]^{-1}\{p_j\}^2$$

with $[T_{ij}]$ the matrix of the transfer functions, $\{Q_i\}$ the vector the volume velocity sources and $\{p_j\}$ the pressure at the field microphones. A similar process was used to evaluate the exhaust sound power.
All measurements were performed in a hemi-anechoic room while tire measurements were performed directly on a General Motors tire test bench.

2.4. Receiver quantification and validation

In the source-path-receiver approach once sources and paths are available, regardless if they come from test or simulation, it is possible to calculate the receiver acoustic performance.
Sound pressure levels were then computed for all receiver positions and source contributions evaluated. As expected and shown by results in function of position tire contribution plays a very important role (Fig. 7). Results were also analyzed at a specific position on the track in the frequency domain showing again the important role of tire contribution on the Pass-by Noise performance (Fig. 8).
An outdoor Pass-by Noise test campaign was performed at General Motors proving grounds by measuring only total sound pressure level vs position.
First simulation results compared to test measurements showed higher level than expected highligthing that it is crucial to correctly take into account real acoustic treatments and correct road impedance.
Generic values for the impedance of the road, the engine cavity and wheel wells were added to the BE model and the model was solved again to get new FRFs.
Different configurations were studied in order to obtain a better correlation for all transfer functions. Finally test results were matched. However, a large number of iterations had to be simulated due to the lack of availability of an accurate description of the sound package information.

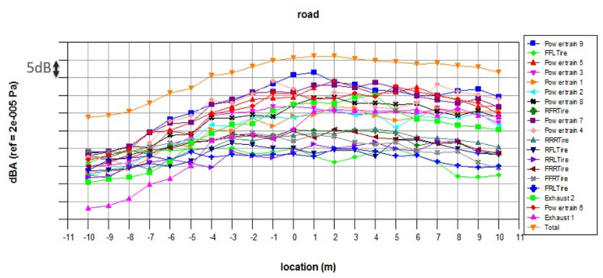

Fig. 7 Pass-by Noise results and contribution analysis in the road domain.

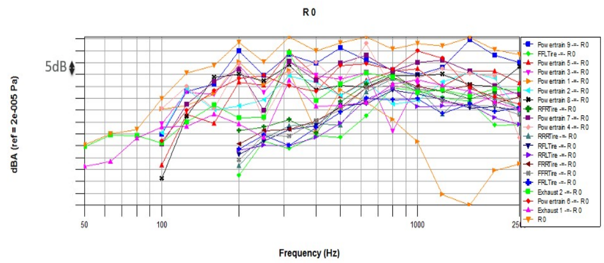

Fig. 8 Pass-by Noise results and contribution analysis in the frequency domain.

3. CONCLUSION

Simulating Pass-by Noise during vehicle development will help take into account the new exterior noise requirements earlier during the development phases.
Design alternatives that may affect the pass-by performances can be evaluated and the design decisions can then be driven by multi-attribute balancing. Contribution analysis will play a crucial role in prioritizing potential countermeasures.
This project has shown that simulation using BE method in conjuction with measured sources can be used to obtain relative comparisons and contribution analyses with good correlation vs. measured transfer functions. Absolute prediction of the Pass-by Noise fail/pass concept are still premature if all acoustic treatment properties are not available and remain a future objective for the simulation .

4. ACKNOWLEDGMENT

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