Modeling and Validation Processes of an Electric Vehicle with Statistical Energy Analysis

Artun Bötke
Hexagon Studio, Kocaeli, Turkey.

Emin Erensoy
Hexagon Studio, Kocaeli, Turkey.

Caner Sevginer
Hexagon Studio, Kocaeli, Turkey.

Summary

The importance of vibroacoustic studies have been increasing consistently in the automotive industry in recent decades. CAE (Computer Aided Engineering) tools are required in these studies to be involved in engineering process of early R&D (Research & Development) stages. To be able to guide the design, full vehicle model and analyses are to be performed confidently from vibroacoustics point of view. FEA (Finite Element Analysis), the most traditional CAE tool in the industry, fails to give confident results in mid and high frequency bands. Therefore, a novel CAE tool called SEA (Statistical Energy Analysis) has been used to overcome this incapability of FEA and analyze vehicles accurately.

Engine noise is not dominant in the electric vehicles as in ICE (Internal Combustion Engine) vehicles. Consequently road noise and wind noise, which contain random excitations, have become the main contributors of vehicle interior noise. The randomness of these noise sources increases considered frequency bandwidths and these sources can be radiated from any location of the vehicle. Therefore, controlling acoustic package of the vehicle has become primary issue for electric vehicle NVH development.

This paper outlines an overview of virtual model building, analyzing, testing and validation processes of acoustic package of the electrical vehicle, V1 Concept, to emphasize the increasing importance of performing SEA in these situations.

1. Introduction

Investigation on sound and vibration has been expanded due to the increased popularity of passenger comfort issue. As well as other important issues, quieter and more comfortable vehicles are required. When this demand meets with increased computer technology and competition in automotive market, usage of CAE tools has increased participating of automotive engineers in early stages of vehicle R&D processes.

The most extensively used CAE tool is FEA which serves multiple engineering disciplines. However, FEA is incapable of satisfying all aspects of noise and vibration issues. First of all, it does not take into account of viscoelastic losses by solving acoustic equations linearly. This assumption causes increasing error margins in mid and high frequency bands. Secondly, nonlinear acoustic parameters, which are very important for determining acoustic performance of vehicle sound package, cannot be included [1]. Lastly, FEA needs detailed geometric models which make modeling expensive and difficult in preliminary stages. Consequently, a different CAE method is necessary to overcome limitations of FEA. SEA is the engineering approach which uses energy equations to simulate sound transfer in vehicles.

Another advantage of this new CAE method is its convenience for electric vehicles, which create a new challenge in NVH characteristic of the vehicles as they have very low engine noise. On contrary, the most dominant noise is engine noise in ICE (Internal Combustion Engine) vehicles. In these vehicles, engine makes such a high noise that it masks road and wind noises, especially in low speeds. However, due to the fact that electric engine makes lower noise than IC engines; road noise, wind noise and other noises like S&R (squeak and rattle) become prominent [2, 3].

Another crucial point is while engine noise has a fixed excitation in frequency domain, sound sources like wind noise and road noise have random excitations. Therefore, investigation over much wider frequency bands is necessary, especially in mid and high ones. Furthermore, since the location of engine is definite, sound insulation around engine compartment has become much more important in ICE vehicles. But in electric vehicles, location of the source is totally indefinite because of its randomness [4]. Therefore whole vehicle and whole sound insulation package have to be analyzed which increases modeling size and running time of the model in a traditional CAE tool. Due to these reasons, using SEA in investigating inner acoustic package is one of the most significant studies in the electric vehicles.

In this paper, the authors summarize modeling and analyzing a vehicle with SEA, testing in various scenarios and validation process of the model with tests in the aspect of being an electric vehicle. Afterwards, reasons of error margins in validation have been also investigated to understand the method, its application style and have a technical background for possible future studies.

2. Model Building

In this study, an electrical and right-hand drive taxi version of Concept V1, shown in Figure 1, was investigated. To model and analyze the vehicle virtually, VA One, SEA product of ESI, is used as engineering software.

Figure 1. Concept V1.

First of all, a modeling strategy, specific for Concept V1, has been formed. There are several parameters which lead to this strategy: Unique glazed roof structure of Concept V1, being an electric vehicle, test scenarios, extensity of inner space, a division of inner space by a partition and modeling factors regarding SEA such as keeping plate subsystems as big as possible [5, 6, 7, 8, 9].

Secondly, 3D CAD model of the vehicle was imported into an FEA software to create coarse nodes and elements. This FE model then was imported into VA One and SEA plate subsystems were created considering the modeling strategy. Inner and outer cavity subsystems were also created in relation with these subsystems. In Figure 2, all SEA subsystems can be seen.

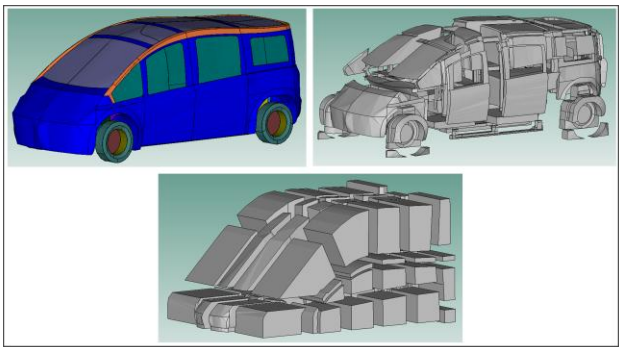

Figure 2. SEA subsystems of the vehicle

As a final step to build SEA model of the vehicle, material samples were collected and sent to a material laboratory to obtain their acoustic material parameters, such as porosity, tortuosity and damping loss factor. These parameters were assigned to each material in the virtual model. However, samples from all materials could not be obtained due to subcontractor problems, which lead considerable error margins in the results.

3. Tests and Analyses

Physical tests were also conducted to form boundary conditions for analyses and validate the virtual model. Tests were performed in two different conditions to ensure the validation and understand NVH behavior of an electric vehicle.

First condition is a controlled environment. In a semi-anechoic chamber, a constant spherical sound source between 100-10000 Hz was placed in front and rear regions of each tire by two different output nozzle; a simple nozzle, which behaves as if it is a point sound source, and a tire patch. The sound source was identified as the boundary condition in analyses. Measurements, taken at rear and driver seats with an artificial head, were used as results.

Second condition is the track, a closed traffic outer environment. In this track, the vehicle is driven at three constant speeds; 10 kph, 20 kph and 40 kph.

Measurements, performed at tires and engine compartment, applied as boundary conditions or noise sources. Measurements, performed at the rear seat with an artificial head and driver seat with a microphone, identified the receiver points.

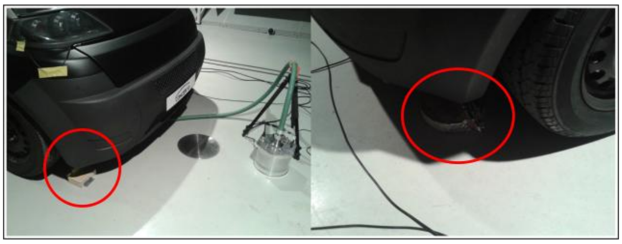

Figure 3. Nozzle placement examples at test in semi-anechoic chamber.

Figure 4. Tire patch placement example at test in semi-anechoic chamber.

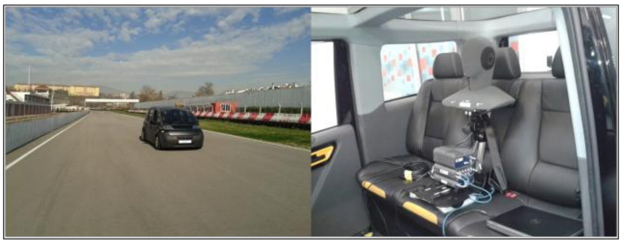

Figure 5. Test at the track and the artificial head in rear seat of the vehicle.

Sound pressure levels [dB(A)], obtained from measurements as stated previously, were transformed into sound energy levels (W) with a linear equation (Eq. 1) [10] and these values were injected in related cavities in the virtual model.

$$SWL_{test} = \left(\frac{SPL_{test}}{SPL_{1W}}\right)^2 .1W \qquad (1)$$

4. Results

As there are lots of load cases and result graphs, only one result graph is shown for each condition.

Result graphs for test with a simple nozzle at semi-anechoic chamber

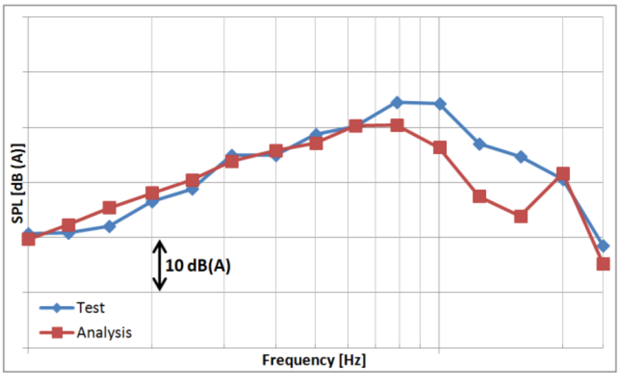

Figure 6. Rear region of front right tire to left ear of rear passenger.

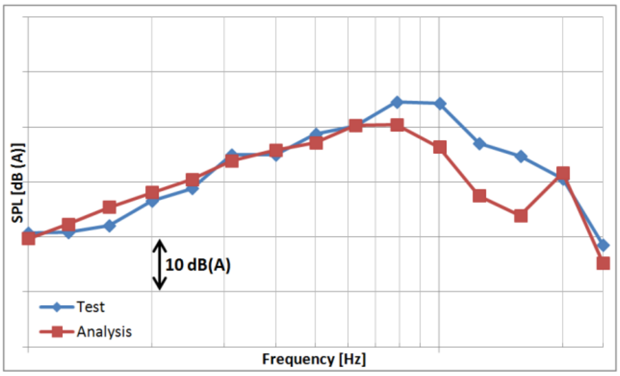

Figure 7. Rear region of front left tire to left ear of rear passenger.

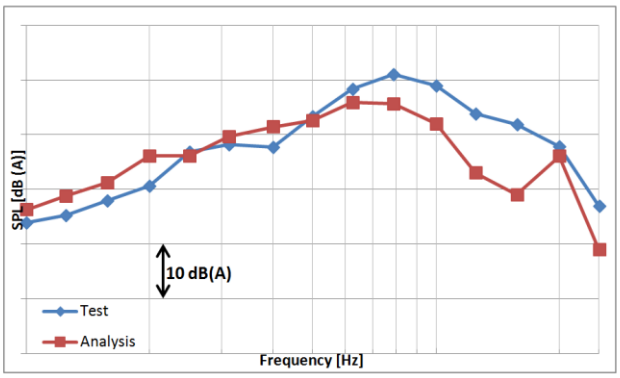

Figure 8. Front region of rear right tire to left ear of rear passenger.

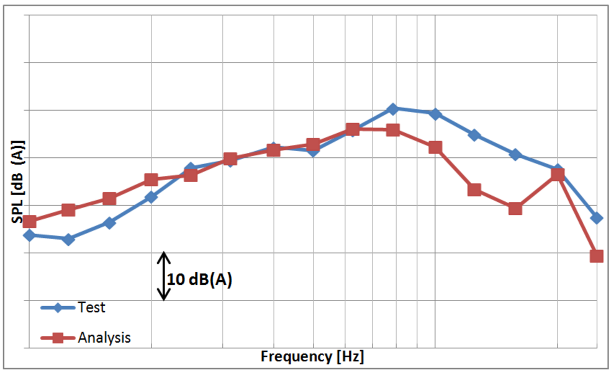

Figure 9. Front region of rear left tire to right ear of rear passenger.

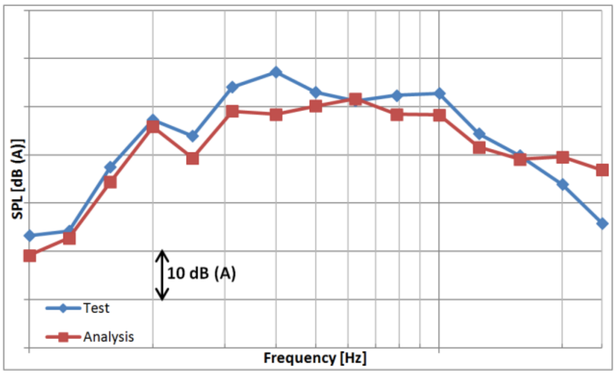

Figure 12. Front region of rear right tire to left ear of rear passenger.

Result graphs for test with a tire patch at semi-anechoic chamber

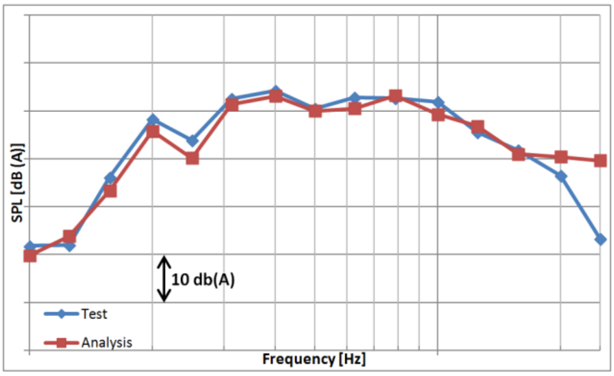

Figure 10. Rear region of front right tire to right ear of driver.

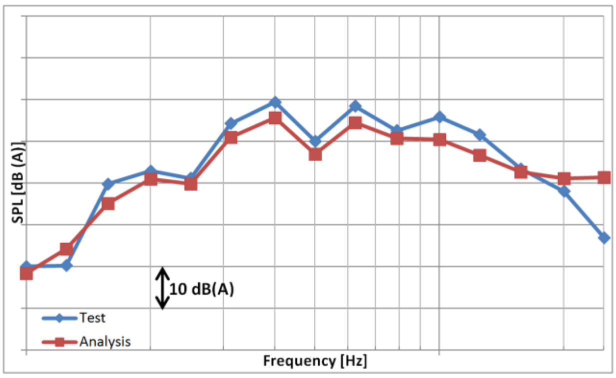

Figure 11. Rear region of front left tire to left ear of driver.

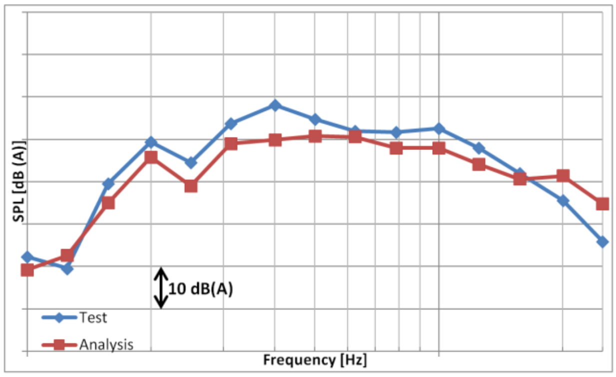

Figure 13. Front region of rear left tire to right ear of rear passenger.

Result graphs for test at the track

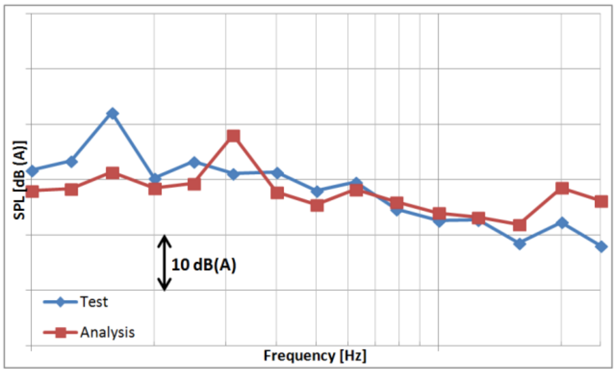

Figure 14. Response at right ear of driver @10 kph.

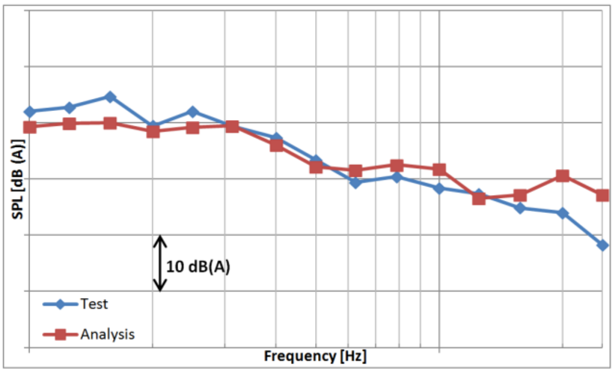

Figure 15. Response at right ear of driver @20 kph.

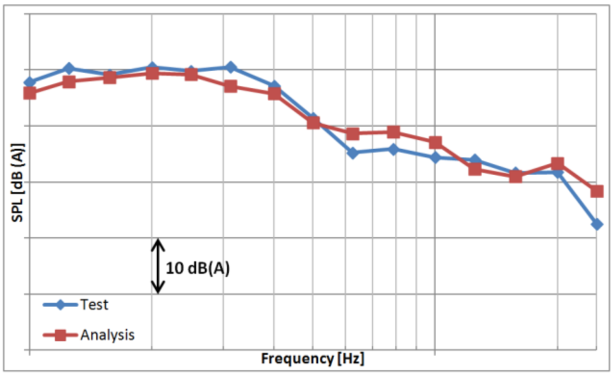

Figure 16. Response at right ear of driver @40 kph.

5. Discussion

Error margins, up to 10 dB, are seen in the result graphs. Causes of these margins can be divided into two main categories; dependent and independent causes from the method. Former category causes ±3 dB error margin and its factors are:

- It is accepted that there is linear connection between SEA subsystems. However, acoustic material parameters are nonlinear. To avoid this situation, acoustic material parameters should be obtained for all trim materials and assigned in virtual model [11].
- Equipartition of energy means that each mode exhibits equal energy, which gives an upper bound to response [9].
- Inner and outer air is divided into subsystems. It is accepted that each subsystem has equal energy level inside and has different energy level from adjacent subsystems [8].

Second category includes error reasons which are independent from the computation:

- As said previously, samples of some materials could not be obtained. So generic parameters were used instead of real parameters in these materials [12]. This situation is the main contributor of error margins.
- In a vehicle, door/window weather-strips and seals are two of the main contributors in sound transmittance. In an ideal SEA model, weather-strips and strips should be modeled separately and a special test should be conducted to obtain their 'acoustic transmittance coefficients'. Because this need came out towards the end of modeling process and there were budget and organization limitations, weather-strips and seals could not be modeled. Only 'slit' was defined at related subsystems to minimize the error.
- SEA is a very user dependent method [11]. User's experience affects directly accuracy of model and modeling speed. User dependent errors were tried to be minimized by communicating with an experienced engineer in ESI constantly during whole modeling process.
- Leakage points of the prototype could not be modeled in CAE tools completely. Therefore, test results could be disagreed from results of the analyses.

Although electric vehicles give the opportunity to eliminate ICE related noise sources and reduce the noise emissions; other noise sources, road surface – tire interaction noise (road noise), wind noise and S&R (squeak & rattle) issues, still remain. Therefore, interior sound evaluations should be performed according to these aspects in higher and wider frequency bandwidths than ICE vehicles. Engine presence also covers most of the accessories noise in ICE vehicles. However, electric motor could not cover these kinds of accessories' noise due to its noise level. During tests, accessories like steering pumps, which are normally not identified during ICE vehicle drive, observed. Then, these new NVH conditions will be studied in further development stage of Concept V1.

6. Conclusion

In this study, an electric vehicle, Concept V1, has been modeled and analyzed by SEA method. In the meantime, physical NVH tests have been conducted on the prototype vehicle. Results of analyses and tests have been compared to validate SEA model and understand NVH behavior of an electric vehicle.

Error margins up to 10 dB have been seen between result values of analyses and test measurements. Causes of these errors have been investigated thoroughly. Difference of NVH behavior of a vehicle due to having an electric engine, instead of ICE, has also been discussed. Further acoustic pack studies will also be carried out as the next step.

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