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EXPERIMENTAL VERIFICATION OF FULL VEHICLE SEA MODEL

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Abstract

Statistical Energy Analysis has been applied widely to improve the accuracy of the prediction of vehicle interior noise. Especially, in airborne noise cases, SEA is very useful for predicting the Interior noise of a vehicle if some parts of the vehicle model are changed. In this paper, a building and validating process of the full vehicle SEA model is presented. First, Sound Transmission Loss and Absorption Coefficient (α) of vehicle components are measured using a real vehicle. An airborne SEA model is built using the geometry information, and the component characteristics are modeled using STLs and α's, which are measured or calculated. For the validation of the SEA model, the interior and exterior noises of a full vehicle were measured for various experimental conditions such as WOT (wide open throttle) condition and loudspeaker loading conditions. Finally, the predicted and the measured interior noises are compared, and the accuracies of the SEA model are identified for several loading conditions.

1. INTRODUCTION

Statistical Energy Analysis (SEA) has been considered an important subject especially for the mid-high frequency range. It is important to accurately predict the SPL at the driver's headspace to estimate the performance of a vehicle without making a prototype vehicle. Using SEA for the interior noise prediction of a vehicle, an automotive company can shorten the development time of a new model in the automotive industry, which is in line with the demands of the rapidly changing market.

A full vehicle SEA model has been demonstrated in a reference [2]. This SEA model was effective in well-controlled load cases. However, it needs to be extended to actual driving conditions and also it is important that the SEA model can be established and verified using the transmission loss result and the absorption coefficients of vehicle components. In this paper, we deal with the verification of the SEA model in the loudspeaker loading condition and extend the application of the SEA model to the driving condition, which is similar to the real working condition of the vehicle.

2. STATISTICAL ENERGY ANAYLSYS

Statistical Energy Analysis is based on the equilibrium power balance between coupled subsystems. It also considers energy transfer. Therefore, the response of a system in a certain frequency range can be analysed [2]. Consider two subsystems that are coupled, as shown in Figure 1. They can share dynamic energy, and the power balance relation can be applied to two subsystems, *i* and *j* [1, 7]. The power balance equations can be written as:

$$P_i = \omega\eta_i E_i + \omega\eta_{ij} n_i \left(\frac{E_i}{n_i} - \frac{E_j}{n_j} \right) \tag{1}$$

$$P_j = \omega\eta_j E_j + \omega\eta_{ji} n_j \left(\frac{E_j}{n_j} - \frac{E_i}{n_i} \right) \tag{2}$$

where ω is the center frequency of the analysis band, P_i is the time-averaged power input from the applied excitations, E_i, n_i, and η_i are the energy, modal density, and damping loss factor, respectively, and η_{ij} is the coupling loss factor from the ith wavefield to the jth wavefield. In this research, AutoSEA2 software was used to predict space- and frequency-averaged SPLs of the vehicle model.

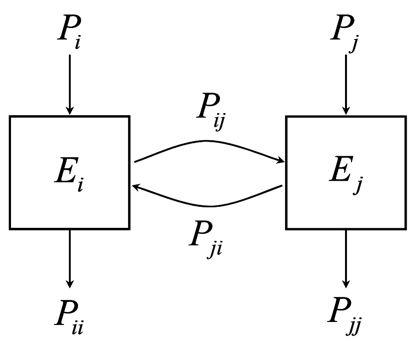

Figure 1. Coupled SEA subsystems

3. SEA MODELLING AND MEASUREMENT

3.1 SEA Modelling

The geometry, material properties, cavities, leakage, and sound package of the vehicle are used to generate an SEA model in AutoSEA2 [7]. First, an SEA model of a vehicle is generated by using FEA/CAD geometry. SEA model should be similar to a real vehicle used in the experiment. Then, the material properties including density, flow resistivity, porosity, Young's modulus, etc., and acoustical properties such as transmission loss and absorption coefficient must be input to complete the SEA model. The material properties were obtained by using in-house software, HONUS2005, to estimate the material properties and to predict the material performances such as transmission loss and absorption coefficient of acoustical materials [6].

The transmission loss was measured by the intensity method and the absorption coefficient was measured by α-cabin. The parts that use the measured transmission loss values are doors, windshield, windows, backlite, dash board, etc. [8]. The measured absorption coefficient value was used at the headliner, seats, floor, etc. The transmission loss is valid from 100 Hz to 6.3 kHz and the absorption coefficient is valid from 400 Hz to 10 kHz. Lastly, the leakage of SEA model is considered according to the geometry of the vehicle.

Except for the engine cavities, the cavities in an SEA model to which the transmission loss and absorption coefficient are assigned, are under conditions that are identical with those of an actual experiment. The engine cavities consist of six cavities: upper, lower, left, right, front and back cavities. The centers of the engine cavities are void. The conditions of the SEA model, which is complete with cavities, are set to the experimental conditions. The exterior cavities of the SEA model, except for the lower cavities, are set to the infinite field to provide the identical circumstances of the experiment to a vehicle in the semi-anechoic chamber. Finally, the measured SPL distribution is set in the exterior cavities. Figure 2 shows the final SEA model.

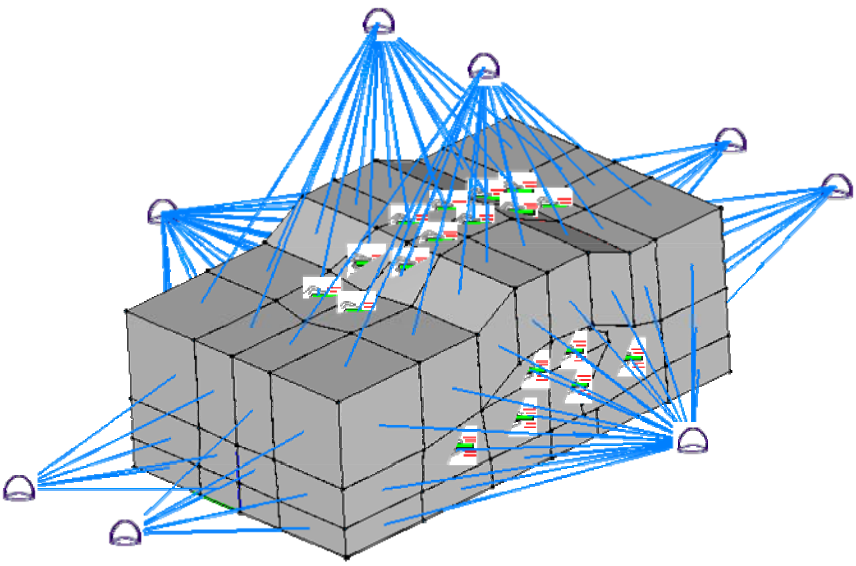

Figure 2. Final SEA model

3.2 Measurements

Experiment was undertaken in a semi-anechoic chamber with chassis dynamo. SPL data was measured with three microphones per cavity, which were used to obtain the space-averaged SPL at the exterior and interior cavities of the vehicle, as illustrated in Figure 3. Because there were more than 160 measuring points, the reference point was determined as the driver's headspace to maintain high reliability. Jig was also used to measure SPL at identical locations every time.

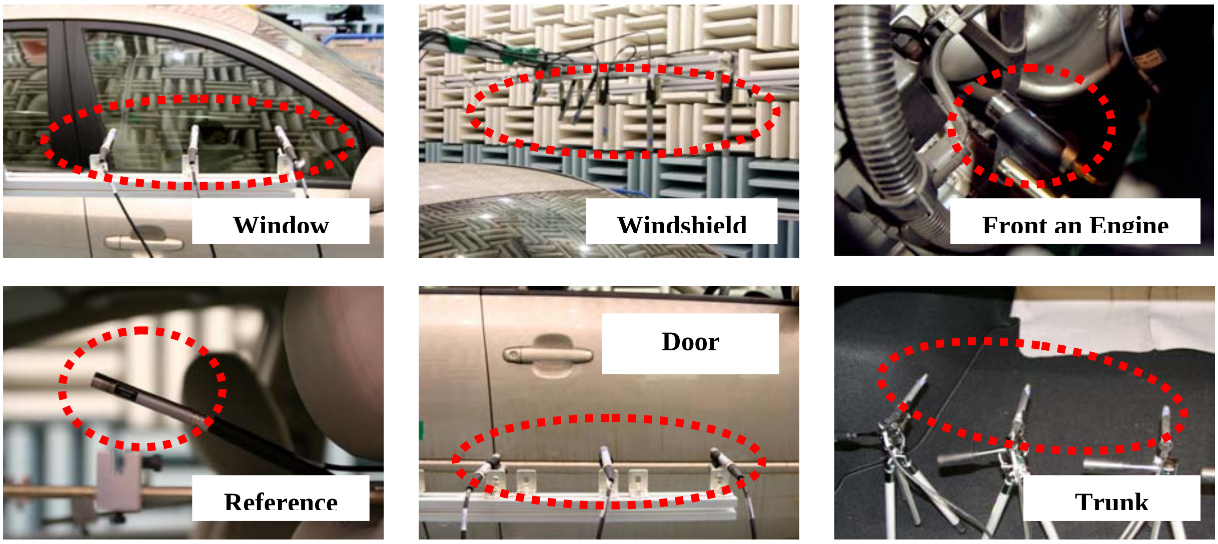

Figure 3. Microphone locations

Two conditions were considered to measure the SPL distribution. One was the driving condition, and the other was the loudspeaker loading condition. The effectiveness of the experiment validated the use of the loudspeaker loading condition [2]. Table 1 shows the driving condition and the loudspeaker loading condition.

Table 1. Measurement Condition

	State	Condition
Driving	Wide Open Throttle (WOT)	2000 rpm ~ 5500 rpm
Loudspeaker	Engine Room	Omni-Power Loudspeaker
	Under a Floor	Baffled Loudspeaker
	Front Wheel	Omni-Power Loudspeaker

Loudspeaker locations were determined considering directivity pattern of the source. As shown in Figure 4, the omni-power loudspeaker was located at the center of the engine room, where the engine was removed in the engine room condition. The loudspeaker operated from 0 Hz to 8 kHz using random noise. SPL was measured in one-third octave bands between 400 Hz and 6.3 kHz.

Figure 4. Loudspeaker locations

3.3 Analysis of the SEA Model

The SEA model was analysed for the driving condition and the load condition by using the loudspeaker. The measured SPL from the exterior cavities was used to create a load set in the SEA model. From these constrained cavities, the SPL of the interior cavities was predicted. The interior cavities consisted of the interior cabin and trunk. Figure 5 shows the exterior cavities, which were constrained.

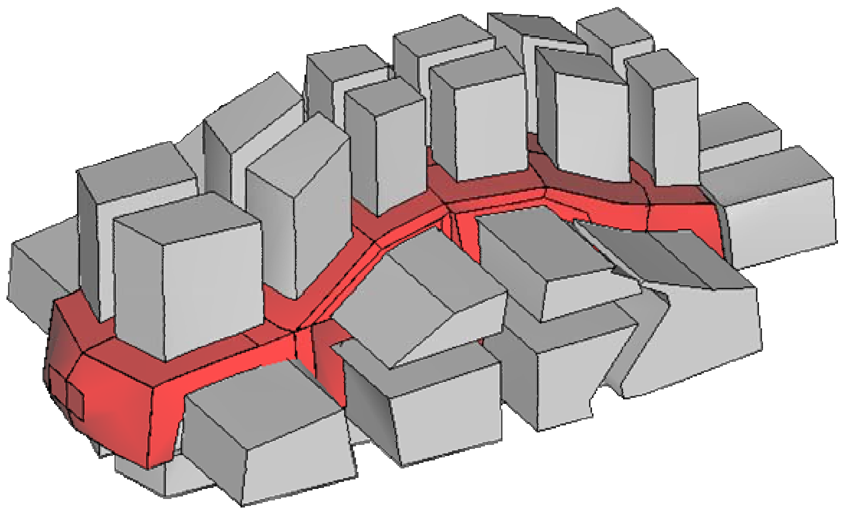

Figure 5. Exterior cavities which are constrained with measured SPL

4. RESULTS

The SEA model was verified using the prediction and experimental results of the loudspeaker loading condition in the interior cavities. The interior cavities, which were measured, can be distinguished into locations, such as the headspace, waist level, legroom, trunk, front seat, rear seat, left side, and right side. As evident from Figure 6, the SPL of the interior cavities was within an accuracy of about 3 dB in the one-third octave bands between 400 Hz and 6.3 kHz. The tendency of predicted and measured SPL is similar according to the location of the cavities. Especially, there is no difference of SPL due to a right seat and a left seat at the same location, such as the headspace, waist level, etc. Figure 6(a) and Figure 6(b) show the results obtained using a typical loudspeaker, while Figure 6(c) and Figure 6(d) show the results obtained using an omni-power loudspeaker. Even though different types of loudspeaker were used, the accuracy of the SEA model could be verified.

After the SEA model was verified, the results for the driving condition were also regarded as accurate. The measured SPL was in good agreement with the predicted SPL, regardless of the driving condition as shown in Figure 7 and 8. However, the results in the driving condition indicated that the measured SPL was in poor agreement with the predicted SPL below the 800 Hz region compared to the loudspeaker loading condition, which were in good agreement with the predicted SPL between the 500 Hz and the 800 Hz range. In this region, the structure-borne noise affects the measured SPL more than the air-borne noise. Depending on the engine type, the regions that are affected by structure-borne noise change. The driving condition can also affect the measured SPL. Because of this, the results can be considered reliable from 800 Hz.

The effect of the air-borne noise can be considered in the loudspeaker loading condition. From these results, we can conclude that the full vehicle SEA model is valid within certain frequency ranges depending on the loudspeaker loading conditions and the WOT condition.

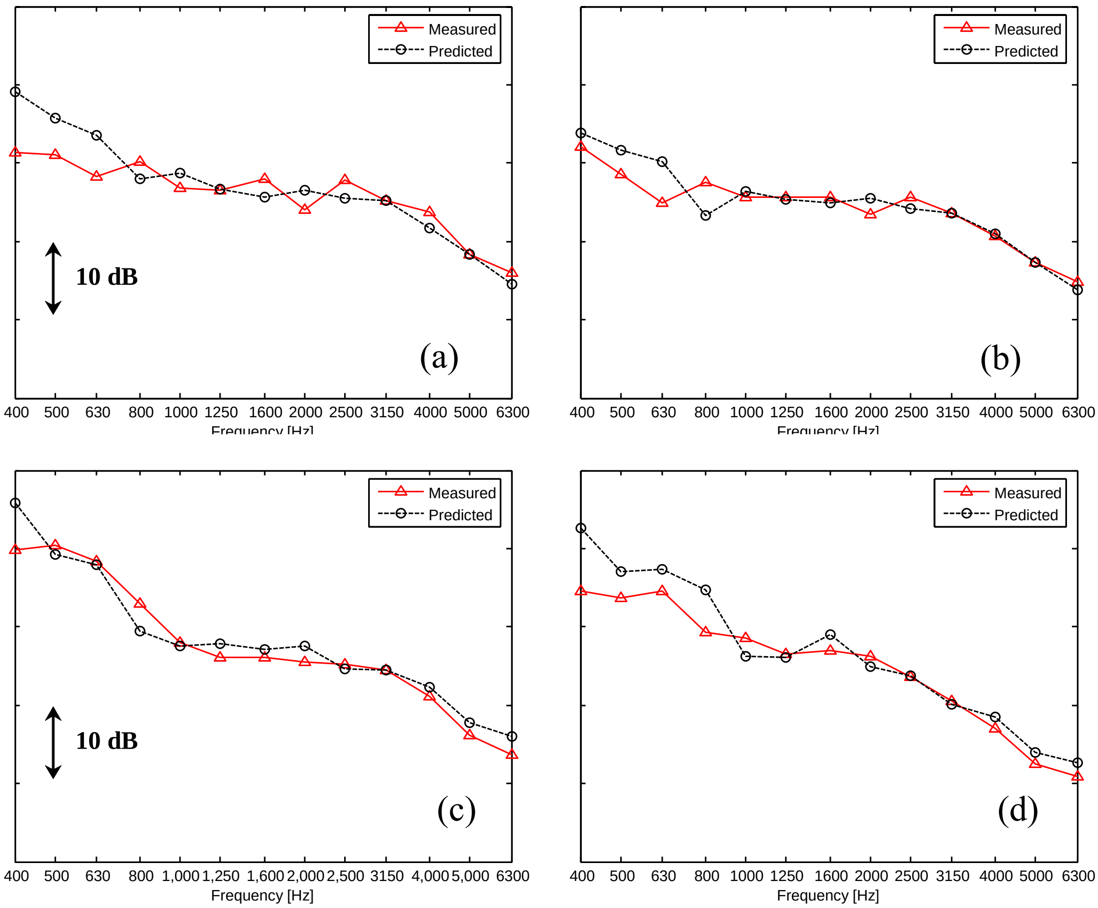

Figure 6. Interior cavities measured and predicted SPL for loudspeaker loading condition: (a) Front seat headspace: located under the floor; (b) Back seat waist level: located under the floor; (c) Back seat legroom: located under the front wheel; (d) Inside trunk: located under the front wheel

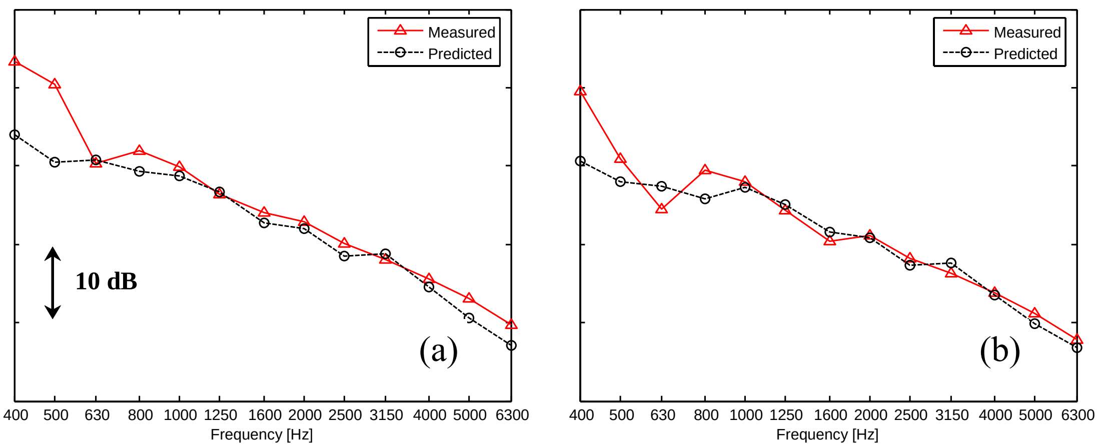

Figure 7. Interior cavities measured and predicted SPL for driving condition: (a) Front seat headspace in WOT condition; (b) Back seat waist level in WOT condition

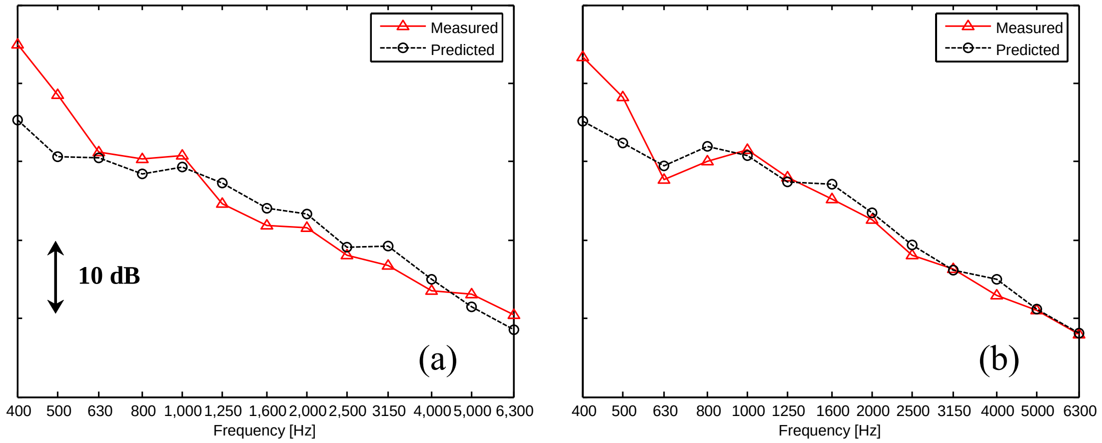

Figure 8. Interior cavities measured and predicted SPL for driving condition: (a) Back seat legroom in WOT condition; (b) Inside trunk in WOT condition

5. CONCLUSION

This paper shows the comparison between the measured SPL and the predicted SPL for two main conditions, namely, the driving condition and the loudspeaker loading condition. The full vehicle SEA model was verified by using the loudspeaker loading condition. According to the verification result, the SEA model was applied in the driving condition by using the same method used in the previous experiment. Depending on the conditions, the range of the reliable frequency was defined. In the driving condition, the measured SPL was mainly affected by structure-borne noise below 800 Hz. In the frequency range affected by air-borne noise, the measured SPL was in very good agreement with the predicted SPL, regardless of the driving condition. In conclusion, the full vehicle SEA model, which was verified, can be used for the driving condition. It can predict the SPL of the interior cabin accurately for a wide frequency range.

ACKNOWLEDGEMENTS

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