SEA as Tool in Vehicle Development

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Abstract

Statistical Energy Analysis (SEA) is a method for calculating higher frequency interior cavity acoustics. Application of the method relies on high modal density subsystems, into which the whole dynamic system must be broken. This induces a lower frequency bound, which is in contrast to finite element or boundary element methods, which are most useful when vibrations of structures or fluids are dominated by individual modes. After an introduction into the SEA theory the applicability of the method in vehicle development will be assessed on the basis of some examples.

Introduction

Over recent years, the use of SEA within the Automobile industry has begun to be accepted as a useful tool for assessing methods for the control of airborne noise.

SEA is indeed an excellent tool for the prediction of the effects of adding absorption and mass to specified vehicle noise paths. In general, therefore, SEA is most commonly used for modeling specific sections of the vehicle (such as a firewall or door) in order to examine the transmission loss through particular panel and sound package combinations.

This is not using SEA to its full potential, there are often several paths for noise into a vehicle and to consider only a single transmission loss path is to ignore potentially more serious routes. In order to sensibly consider the overall noise levels within a car, it is necessary to model the whole vehicle.

In addition, the noise paths within a car comprise airborne as well as structure borne noise. Most SEA applications however restrict themselves to airborne phenomena, which may appear to be the most reasonable usage, based on SEA theory. Our investigations in real world applications have shown that also structure borne effects can be assessed within necessary accuracy, provided that the models are detailed enough.

This paper deals with the application of SEA at Audi. After an introduction into SEA theory the individual steps of introducing SEA at Audi and their results are sketched. Examples show, how SEA can support the process in automobile development.

SEA Theory

Power Balance Equations

It is well known that the fundamental mechanical equations can be formulated in terms of energy conservation.

For a steady state, linear mechanical system decomposed into two subsystems this is often illustrated by means of the scheme shown in figure 1.

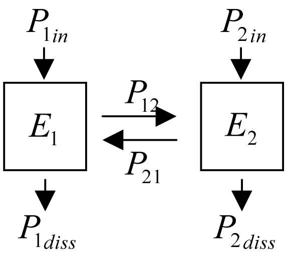

Figure1: Power flow between two mechanical resonators

In this schematic representation E_1 and E_2 denote the steady energies of subsystems 1 and 2 respectively, $P_{1_{in}}$ and $P_{2_{in}}$ the powers fed into the two subsystems, $P_{1_{diss}}$ and $P_{2_{diss}}$ the powers dissipated within the subsystems and eventually P_{12} and P_{21}, which represent the powers exchanged by the two subsystems. These relations are generally valid and hold for each frequency.

Loss Factors

For calculation purposes it is now necessary to relate the powers to the subsystem energies. Formally this can be done by introducing damping loss factors η_i as well as coupling loss factors η_{ij} :

$$\eta_i = \frac{P_i}{\omega E_i}, \; \eta_{ij} = \frac{P_{ij}}{\omega E_i}$$

The critical quantities are the coupling loss factors. Analytical calculation of them imposes essentially two assumptions: the **diffuse field assumption**, which assumes uniform distribution of energy density over each subsystem and equal probability of wave incidence angles at boundaries and the **weak coupling assumption**, which states that for calculating coupling loss factors between two subsystems the surrounding subsystems can be neglected.

From a modal point of view, in contrast to finite and boundary element methods the applicability of SEA relies on high modal densities of subsystems and is therefore related to some lower frequency bound. Our experience shows that for usual passenger cars these bounds are approximately 300 Hz and 400 Hz for structure and airborne noise respectively. This may vary with the excitation considered and whether the transmission is dominated by individual modes, which expand over several subsystems.

SEA Modelling

The models were built using AutoSEA2 [3] and were based on finite element data. The crucial requirements in SEA modelling are to build as large as possible subsystems to respect diffuse field conditions and to locate boundaries of subsystems, where energy is predominantly reflected, to respect the weak coupling assumption. On the other hand, there are requirements related to the degree of detail of results. It is therefore necessary to split the interior cavity of a car into several SEA subsystems to account for spatial distribution of sound pressure.

Our A4 model can be seen in figure 2. It consists of about 630 structural and 170 acoustic subsystems including exterior cavities.

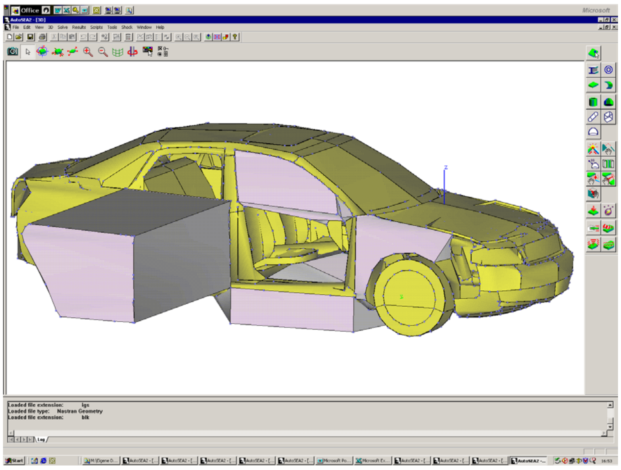

Figure 2: AutoSEA2 model of Audi A4 including some interior as well as exterior cavities

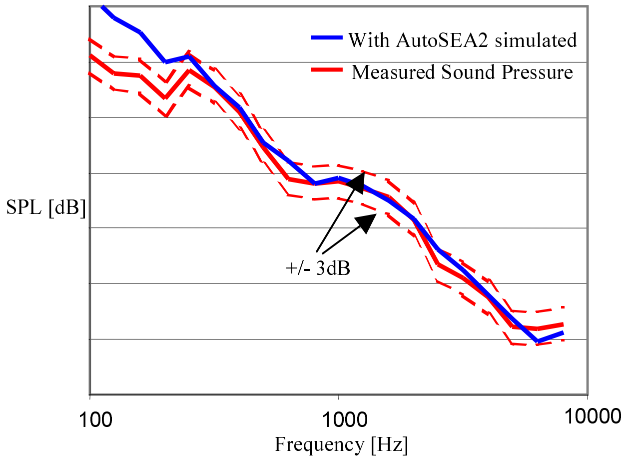

Figure 3: Comparison of simulated and measured interior sound pressure levels on a test track with 50 km/h

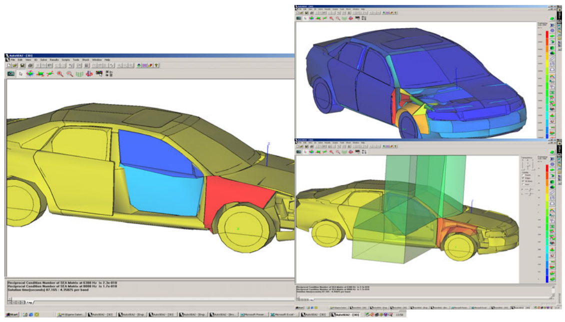

Figure 4: Transmission paths for excitation in the fender cavity including structure-borne path top right

SEA in Automobile Development

Evaluation Projects

We started with a validation project for which extensive measurements were performed beyond simple acceleration and sound pressure level measurements. In addition, elaborate noise decomposition techniques were employed, in order to decompose test track data into individual excitation mechanisms. One characteristic result is shown in figure 3. We see that SEA is capable of reproducing the measured results within the scatter range of measurements.

The second step of evaluation also referred to an existing car. Building the model however we pretended to have a virtual car, which means that no measurements were conducted. In cooperation with our acoustic testing engineers excitation schemes were defined, which were known to be relevant and the task was to detect the transmission paths into the interior of the car. Figure 4 shows three of those paths for white noise excitation in the right fender cavity.

Those studies revealed an interesting structure borne transmission path, which could be confirmed by subsequent measurements.

Development Project

Now SEA is employed in a current development process. The application is based on white noise airborne as well as structure borne excitations. The results are assessed relative to the transfer characteristics of the predecessor car. Most of the investigations are related to conceptual questions: If acoustically relevant parts of the car were modified, how would it affect the acoustic overall performance and – if necessary – how could the modifications be compensated? The capability of SEA to assess such modifications with respect to high frequency interior acoustics in an early development phase, where no prototypes exist, proves extremely useful.

References

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[4] De Langhe, K.: High Frequency Vibrations: Contributions to Experimental and Computational SEA Parameter Identification Techniques, University of Leuven, 1996