Acoustic Simulation of a Coffee Machine using Statistical Energy Analysis

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Introduction

Noise Emission from domestic appliances, especially in office environment, has impact on the well-being of surrounding users. Therefore it is the industries goal to produce silent products. This paper shows the acoustic simulation of a coffee machine using Statistical Energy Analysis (SEA) in VA One. Topics are the composition of the model and realistic reproduction of measurement results, as well as applicability of the SEA Method.

Statistical Energy Analysis

Statistical Energy Analysis was developed over several decades as a result from the pioneering work by Lyon and Smith [1] in the early 1960's. SEA represents a field of study in which statistical descriptions of a system are employed in order to simplify the analysis of complicated vibro-acoustic problems. SEA was originally derived for describing the storage and transfer of vibrational and acoustic energy between subsystems of "weakly" coupled modes. The energy storage capacity of a given subsystem is described by the modal density; the coupling between subsystems is quantified with coupling loss factors while the damping loss factor characterizes energy losses within the subsystem. Applying conservation of energy to each subsystem then results

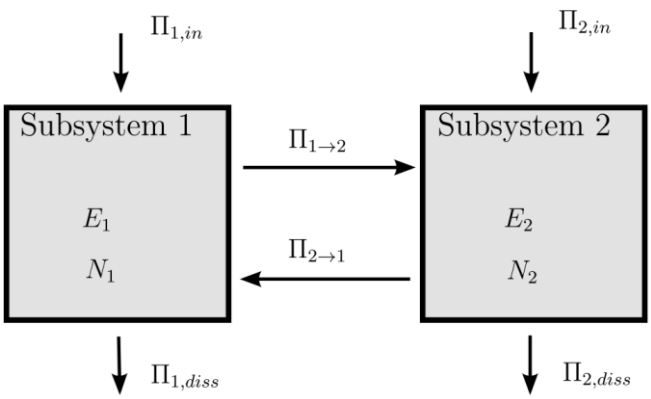

Figure 1: Energy Flow between two Coupled Subsystems

in a set of simple linear simultaneous equations for the subsystem energies as illustrated in equation (1)[1]. Figure (1) shows the energy flow between two coupled subsystems.

$$\Pi_{1,in} = \Pi_{1,diss} + \Pi_{1\to2} - \Pi_{2\to1} \qquad (1)$$
$$\Pi_{2,in} = \Pi_{2,diss} + \Pi_{2\to1} - \Pi_{1\to2}$$

Coffee Machine Model Composition

The SEA model of the coffee machine was built from a Finite Element (FE) model. Structural subsystems were defined according to the Property IDs from the FE model and shape of the structure. The structure then gives a possible definition of the interior cavities, which were modeled with reduced size (and therefore reduced mode count) to consider wires and hoses in the real coffee machine.

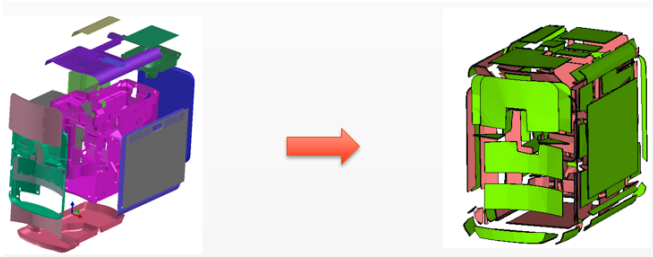

Figure 2: FE Model (l) and SEA Model (r) of the Coffee Machine

The exterior of the coffee machine is modeled with SEA cavity subsystems, including cavities at the location of the microphones to obtain results for validation. A connection of the exterior cavities outer faces to a Semi Infinite Fluid represents anechoic termination.

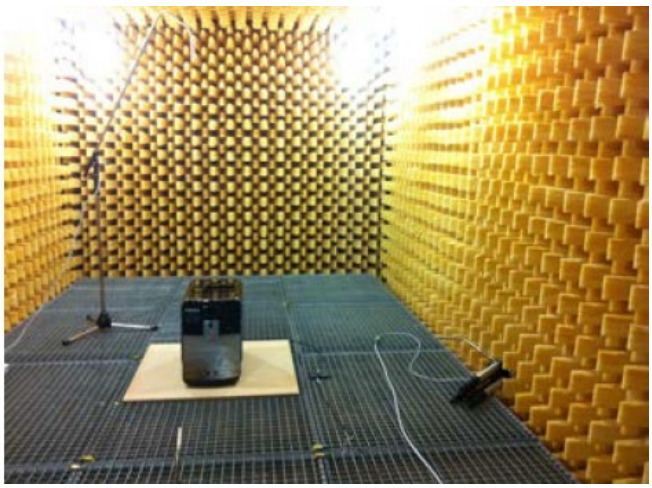

Figure 3: Coffee machine measurement setup in anechoic chamber with microphones

Equation (2)[2] shows the cavity mode count N depending on the wavenumber k, Volume V, Surface S and Perimeter P of the cavity. For exterior cavities not connected to a structure only the first summand of Equation (2) applies.

$$N(k) = \frac{k^3}{6\pi^2} V + \frac{k^2}{16\pi} S + \frac{k}{16\pi} P \qquad (2)$$

The coffee machine sound package was modelled with the measured absorption of the foam material used. The absorption adds to the damping of the interior cavities.

The structure of the coffee machine contains many holes and slits. Some of them are modeled on subsystem level with cavity-cavity area junctions, other smaller ones are represented by leaks in cavity-structure-cavity area junctions. Leaks add transfer paths to the system.

In the context of this paper excitation via loudspeaker is presented. The grinding unit has been taken out and replaced by a loudspeaker. A microphone was placed close to obtain radiated power, which is then power input for the grinder cavity in the SEA model.

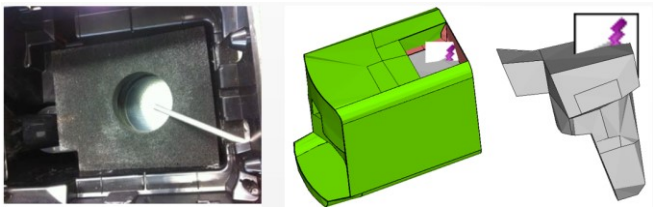

Figure 4: loudspeaker with microphone (r), SEA model (c), grinder cavity with power input (r)

SEA Requirements

Since the SEA model of the coffee machine has rather small subsystems and therefore subsystems with low mode count compared to automotive or aerospace SEA models, it is worth verifying the applicability of the method and the possible error that arises. Here a confidence interval is considered. It is the interval between certain percentile limits on the probability density function of the subsystem response. Statistics of subsystem response depend on mode count, damping and bandwidth.

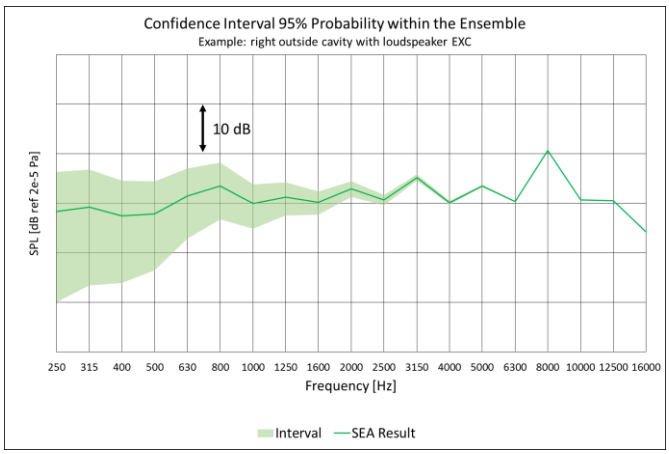

Figure 5: Confidence Interval for exterior cavity

Figure (4) shows the interval of 95% probability and result for an exterior cavity. The graphs indicate convergence around 2 kHz.

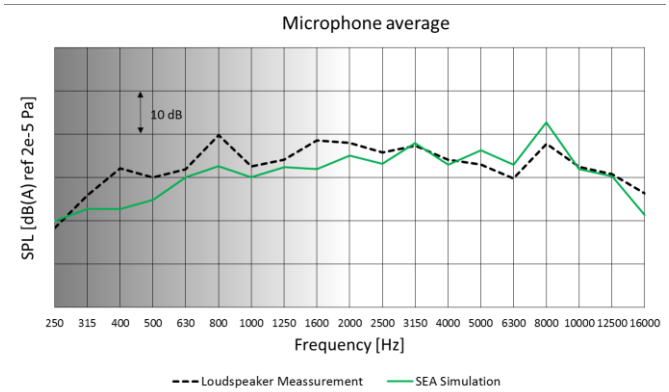

Figure 6: Measurement and simulation average over all exterior microphones resp. SEA cavities at microphone locations

Results Comparison

Result comparison in Figure (6) shows reasonable agreement between simulation and measurement over a broad range of frequency bands. The background coloring refers to the confidence interval from Figure (5).

Further Investigation

Due to its complicated shape the inner chassis, which is one part in reality, was partitioned into numerous small structural subsystems that do not necessarily have as good prediction statistics as other larger subsystems, e.g. the exterior cavity from above. It is now of interest to see whether the partitioning of the chassis affects results.

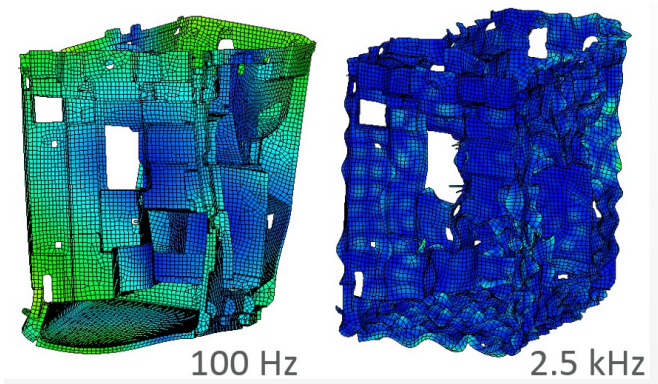

Figure 7: Inner chassis with global mode at 100 Hz and localized mode shapes at 2.5 kHz

For the investigation the SEA model was reconstructed. The inner chassis is now represented by a single SEA subsystem (Figure 8) with the actual modal density from a FE modal analysis instead of several subsystems with modal density approximated by a wave approach.

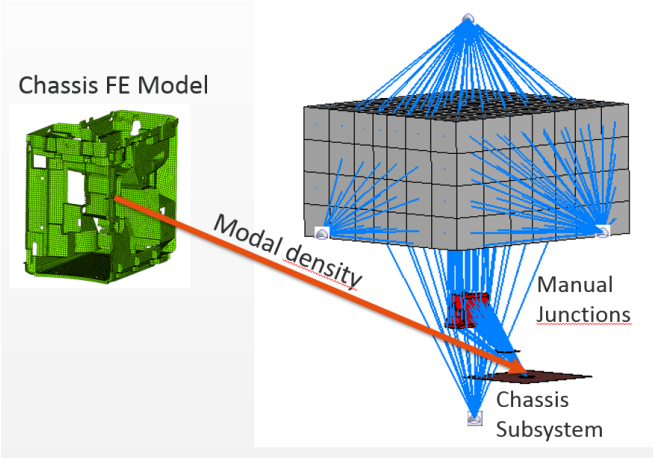

Figure 8: Investigative model: single subsystem chassis with modal density from FE

Figure (9) shows results for the previous model (Multiple Subsystem Chassis) and the investigative Model (Single Subsystem Chassis).

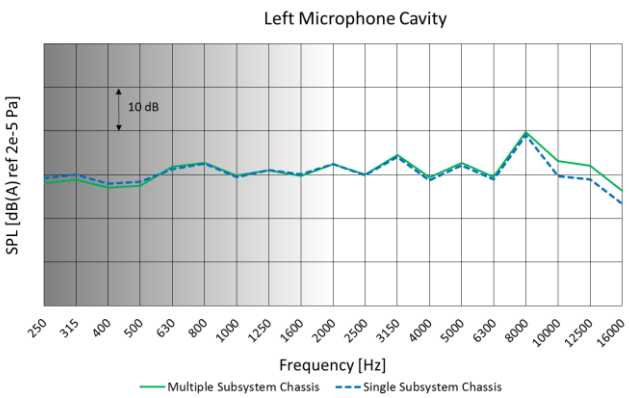

Figure 9: Simulation results for single Subsystem chassis with modal density from FEA and multiple subsystem chassis.

Conclusion

Validation with measurement shows that the SEA simulation delivers feasible results in a broader frequency band than expected. Even partitioning the chassis does not harm the quality of the results. In this case of a purely airborne excited model with power input in the grinder cavity the main energy transfer paths are airborne. Structure-borne transmission through the chassis itself is not dominant with airborne excitation. To summarize it is to say that in this case SEA was used to simulate successfully the acoustics of a smaller object in consideration of limitations of the method.

Literature

[1] Lyon R.H.; DeJong R.G.: Theory and Application of Statistical Energy Analysis. Butterworth-Heinemann 1995

[2] Hopkins C.: Sound Insulation. Elsevier/Butterworth-Heinemann 2007