

A combined modelling approach for improved SEA prediction in automotive applications

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Introduction

For automotive engineers the predictive SEA with tools like AutoSEA and the measuring method of the experimental SEA with e.g. LMS ESEA which is fundamentally based on transfer functions (FRFs) are often two different worlds. A new aspect, which seems to be very promising, is the combination of the analytical and the experimental modelling in order to gain an improved simulation accuracy. This goal can be achieved easily if both the experimental and the analytical modelling processes result in an identical subsystem partitioning. On the other hand MAGNA STEYR's practise has shown that this strict modelling instruction cannot be fulfilled in daily work. Therefore, special techniques for merging these two worlds are outlined in the following.

Reduction/expansion technique

Motivation: The term ‘combined modelling’ describes a process which allows the integration of measured internal loss factors (ILF) and coupling loss factors (CLF) into an analytical SEA model. If the partitioning of the model in subsystems is identical for both the analytical and the measurement model, then the ILF/CLF integration is simple. If this is not the case then one can usually choose out of the following options:

- repetition of the measurement
- regrouping of FRFs, repetition of ESEA calculation
- application of CLF/ILF parameter merging/ partitioning technique

Having costs and engineering time in mind MAGNA STEYR has decided to solve the mentioned conflict by developing a merging/ partitioning technique.

Figure 1 depicts the reduction/ expansion process between two models which consist of 2 and 3 subsystems. The difference between these models represent the partitioning mismatch. While the subsystems 1^{red} and 1^{exp} are identical, the subsystems 2^{exp} and 3^{exp} are merged together to 2^{red}, or the other way around, the subsystem 2^{red} is partitioned. Our basic assumption is that the net power flow related to subsystem 1 and the total energy of the unchanged subsystem 1 is preserved after the transformation. For simplicity we further assume that we only deal with flexure wave types and that no point couplings occur.

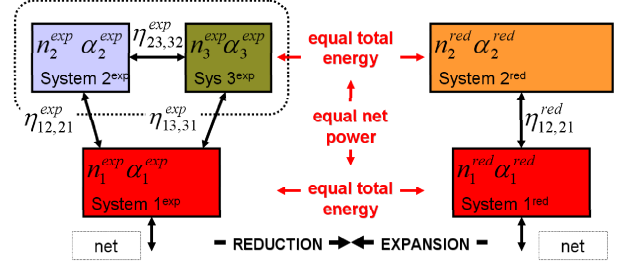


Figure 1: reduction/expansion of a simple SEA model.

Reduction: All the SEA parameters (modal densities $n_{1,2,3}^{exp}$, ILFs $\alpha_{1,2,3}^{exp}$, CLFs $\eta_{12,13,23}^{exp}$) of the expanded model in Figure 1 are given. As subsystem 1 is unchanged we have $\alpha_1^{red} = \alpha_1^{exp}$ and $n_1^{red} = n_1^{exp}$. The modal density of subsystem 2^{red} is calculated by $n_2^{red} \approx n_2^{exp} + n_3^{exp}$. We state the reduction equation as

$$E_1^{red} \stackrel{!}{=} E_1^{exp}, \quad (1a)$$

$$E_2^{red} \stackrel{!}{=} E_2^{exp} + E_3^{exp}, \quad (1b)$$

where the energies E_x are total subsystem energy spectras, see [1, 2] for details. The unknowns α_2^{red} and η_{12}^{red} can be derived out of (1a-b).

Expansion: All the SEA parameters of the reduced system (modal densities $n_{1,2}^{red}$, $\alpha_{1,2}^{red}$, η_{12}^{red}) are given. Again we use $\alpha_1^{exp} = \alpha_1^{red}$ and $n_1^{exp} = n_1^{red}$. The modal densities $n_{2,3}^{exp}$ and the ILFs $\alpha_{2,3}^{exp}$ are assumed to be known as geometry and material properties of the expanded model are usually known. We state the expansion equation as

$$E_1^{red} \stackrel{!}{=} E_1^{exp}, \quad (2a)$$

$$P_{12}^{red} \stackrel{!}{=} P_{12}^{exp} + P_{13}^{exp}, \quad (2b)$$

where P_{xy} is the net power, [2]. The unknown η_{23}^{exp} must be taken e.g. from an AutoSEA calculation. The unknowns η_{12}^{exp} and η_{13}^{exp} can be derived out of (2a-b).

Solving: For solving the problem, the nonlinear least-square method out of MATLAB's optimisation toolbox is used. E.g. for the expansion process out of (2a,b) an optimisation functional is defined

$$f(\eta_{12}^{exp}, \eta_{13}^{exp}, \omega) = \frac{1}{2} \left\| \begin{array}{c} E_1^{red} - E_1^{exp} \\ P_{12}^{red} - P_{12}^{exp} - P_{13}^{exp} \end{array} \right\|^2. \quad (3)$$

Within this functional the SEA energy balance equations for the reduced and the expanded model are solved for a fixed frequency. A source power of 1W at the subsystem

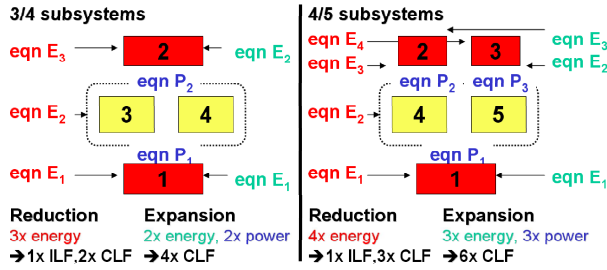


Figure 2: expansion of the concept to more subsystems.

1 is assumed. The coupling topology must be regarded within the SEA matrixes.

Concept expansion: Figure 2 shows how to expand the method to bigger models. An additional energy balance and net power balance equation can be stated for each additional subsystem. For the reduction case the number of energy balance equations is $N - 1$, where N is the number of subsystems. For the expansion case we have $N - 2$ energy balance and $N - 2$ net power balance equations. This correlates with the increase of unknown parameters. At MAGNA STEYR the method is implemented and validated on examples with up to 7 subsystems.

Verification on an example

For verification of the method we used various small example models where we modelled the merging/ partitioning process analytical with AutoSEA. These results were used for verification of our method. E.g. for a model out of 4 or 5 plates respectively and 2 cavities we calculate an error of order 10^{-4} for the reduction and 10^{-3} for the expansion process. The reason might be a truncation error that occurs as AutoSEA can only export parameters with a precision up to 6 digits.

Application

A typical application is depicted in Figure 3. The measurement ESEA model assumed the tailgate to consist of one subsystem. On the other hand the AutoSEA model had to be modelled out of two subsystems because of geometrical problems. This partitioning mismatch can be solved by expansion of the 6 subsystem ESEA model to a 7 subsystem model. The results can then easily be integrated into the AutoSEA model. On the left hand side

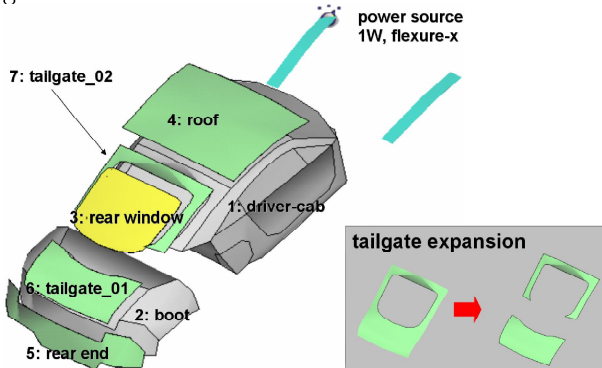


Figure 3: expansion of the ESEA model of the tailgate of a sport coupé

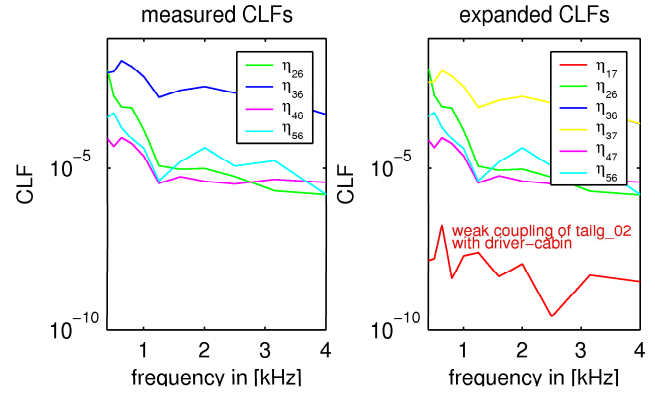


Figure 4: out of measured CLFs (left) new CLFs are calculated (right) using the expansion technique.

of Figure 4 the ESEA CLF spectras can be seen, while the right hand side shows the CLFs after the expansion. Couplings which exist in both models are only changed slightly and the new CLF which couples the tailgate_02 with the driver cabin results in a weak coupling which is expected.

In order to show the differences between predictive and combined modelling we used the whole sports coupé model. For both models we first derived all CLFs with AutoSEA and integrated all ILFs which are known by measurement. In the so called ESEA model we additionally integrated the set of expanded CLFs from Figure 4. Therefore all differences are caused by differences between the CLF parameters. The model was excited with a constant spectral density of 1W at the left longitudinal. In Figure 5 slight differences can be seen for the drivers-cabin SPL (left) while we observe a clear energy mismatch related to the subsystems tailgate_01, tailgate_02 and rear window.

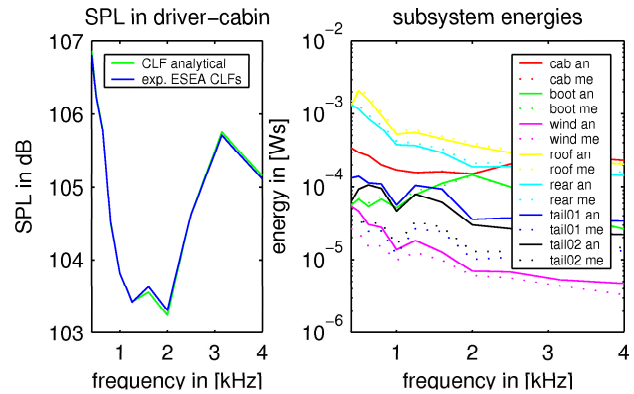


Figure 5: Comparison of combined modelling with analytical modelling.

References

- [1] Theory and Application of Statistical Energy Analysis, Second Edition, Butterworth-Heinemann, 1995
- [2] Statistical energy analysis, Cambridge University Press, 1997