Investigation of Possibilities for Improvement of Hybrid SEA Models with the Integration of Measurement Data

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Introduction

SEA (Statistical Energy Analysis) is a method to calculate the high frequency behaviour of complex structure, which is divided into subsystems. The resulting acoustic characteristics are defined by damping and coupling loss factors. The analytical SEA uses only geometrical and material information and has a high modelling effort and allows only trend predications for package definitions during the concept phase. On the other side there is the experimental part (ESEA) which is based on the measurement of subsystem properties such as damping and coupling loss factors. The ESEA allows a more accurate prediction with a reduced modelling effort but has an high measurement effort and is therefore used in the serial development for vibro-acoustic path analysis and the optimisation for NVH packages.

Hybrid SEA modelling

By combining the analytical and experimental SEA parts we get the hybrid SEA. The analytical SEA model is created from a FE-model using the geometry data and material properties. After applying the measurement we use our in-house tools to calculate all relevant spectra.

Experimental SEA (ESEA)

The most important part for the measurements is the measurement setup, which guaranties that the measurement model matches the analytical model. The measurement list is automatically created from the XML AutoSEA model using a in-house MATLAB tool (SEAPIM toolbox). This list is adapted to measurability of subsystems with the real trimmed body vehicle. If necessary also the AutoSEA model needs to be adapted. In general vehicle symmetries left/right can be assumed which reduces the measurement effort dramatically. Further reductions of measurement effort are reduced by defining of so-called “subsystem sets” which is a group of subsystems which are measured at one time (depends on the available channels of the measurement system). Here it is crucial to find the optimal set. A recommendation is to define the set of subsystems which have many common couplings.

For the measurement the PIM (power injection method) is applied [1]. With this method each subsystem is excited at several times and the responses of all subsystems of a set are measured. During the measurement of the FRFs (frequency response functions) it is very important to monitor specific signals. Which are the coherence, excitation signal (SNR, bandwidth and time) and also the imaginary part of the inertance (a/F) of the excitation point. The measurement of fluid and structural subsystems is done by exciting the subsystems with a volume velocity source and a impulse hammer/ shaker for structural subsystems. A very important aspect of the measurement is to use a standardised labelling schema and a redundant measurement node numbering. This is essential to find and correct errors in the channel setup of one load case (which is possible with the SEAPIM toolbox).

ESEA data management

The measured data are exported into universal files. These files are used to build up the SEAPIM data base which supports a user definable reading interface. This data base contains all measured FRFs, point mobilities and excitation spectra. The toolbox allows many manipulations (e.g. redefinition of subsystems) inspection and correction of measurement data. The main application of the SEAPIM toolbox is the calculation of damping loss factors, coupling loss factors and equivalent masses/ volumes. The toolbox supports the calculation method according to [2]. The spectra are exported to ASCII files which are integrated into the analytical AutoSEA model using the SEANTF toolbox. During the export some checks where performed (smith criterion, strong coupling …). It is also possible to inspect the FRFs and compare magnitude ranges to find possible source of errors.

ESEA of a sound brick

The sound brick is a reproduction of a vehicle and consist of a passenger compartment PC (6.1m³) and an engine compartment EC (1.4m³) build up with 100mm concrete. This reverberant cavities can be divided with a test frame (corresponds a firewall FW). The test frame was equipped with an 0.5 mm steel plate (640x390 mm). For the analysis purpose the EC was excited and the averaged PC sound pressure level was measured respectively simulated (The AutoSEA model of the sound brick is displayed in Figure 1.)

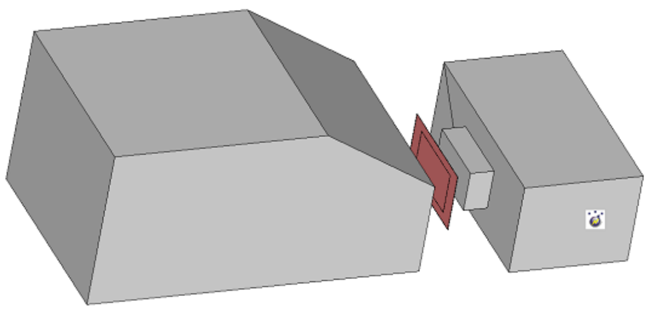

Figure 1: AutoSEA model of the sound brick

In the analytical model EC damping 0.1%, the FW damping 1% and the PC damping 0.1%. The ESEA setup exists of 11 microphones in the PC, 4 in the EC and 7 acceleration sensors on the FW.

Figure 2 depicts the sound pressure levels in dB of the PC if the EC was excited from the measurement (black), the analytical simulation (blue) and the hybrid simulation (red). We can see that the hybrid model is in the target tube (black dashed) +-5dB and represents the measured characteristics very good. The analytical results can not reach the target over the full frequency band.

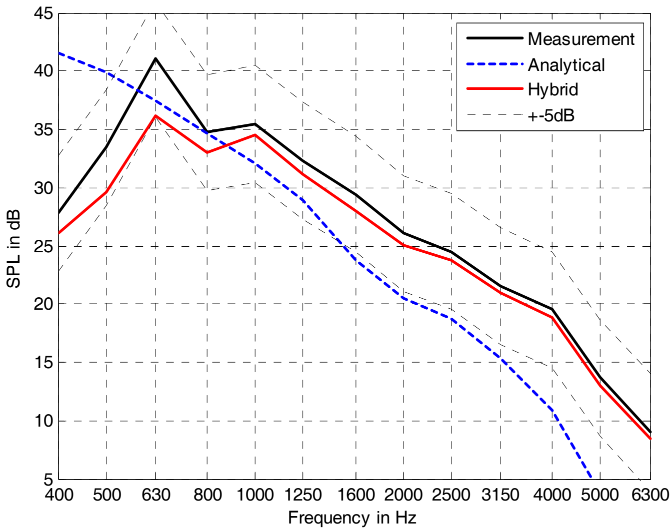

Figure 2: Comparison of analytical and hybrid sound brick model (black measurement, blue analytical, red hybrid sound pressure level SPL in PC)

Alternative calculation of coupling loss factors

Very often the problem arises, that only one direction of a coupling can be measured. Therefore a method is tested to calculate one coupling from modal densities.

From [3] we have the reciprocity relation (1) between coupling loss factors η_{ij} and modal density n_i.

$$\eta_{ij} = \eta_{ji} \frac{nj}{n_i} \qquad [1] \qquad (1)$$

The modal density can be calculated from the averaged real parts of the point mobilities v/F and the mass m of the subsystem (equation 2) [3].

$$n(f) = 4 \cdot m \cdot \left\langle Re\left\{\frac{v}{F}\right\}\right\rangle \qquad \text{[modes/Hz]} \qquad (2)$$

By combining equations (1) and (2) we can calculate one coupling loss factor, if we have the modal densities respectively the point mobilities of each subsystem and the coupling into the other direction.

For the following example the coupling from EC to FW was calculated from structural point mobilities of the FW, the calculated coupling loss factor from FW to PC (ESEA measurement and SEAPIM) and the modal density from the PC from AutoSEA.

The resulting simulation with the coupling loss factor from modal densities from EC to FW is displayed in Figure 3 (green). In the result for the analytical simulation the coupling EC to FW is set to reciprocal in AutoSEA and the other spectra are identical to the hybrid (red) simulation.

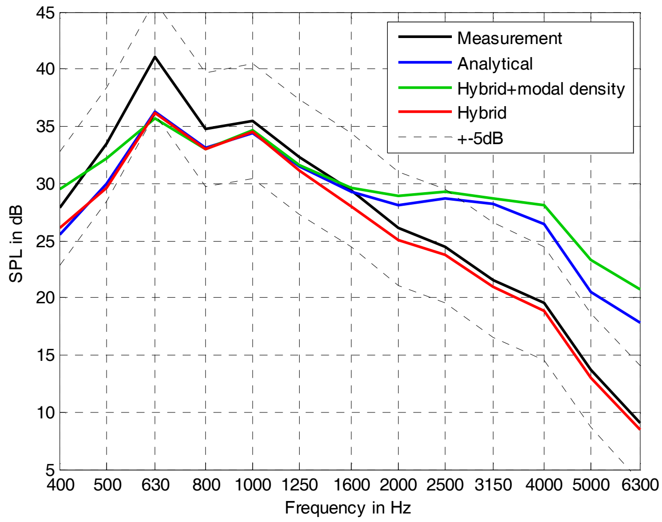

Figure 3: Comparison of PC SPL, measurement black, analytical blue, hybrid with an coupling loss factor calculated from modal density (green) and hybrid red.

We can see that the analytical (blue) simulation is better than the hybrid with the modal density calculation (green). The reason for this could be the simple subsystems as an advantage for the analytical AutoSEA simulation.

Conclusion

We can see that the hybrid SEA modelling results in an improved simulation accuracy compared to pure analytical simulation. A second point describes an alternative way to calculate coupling loss factors from modal densities respectively point mobilities and compares the resulting simulation.

References

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