Methodenvergleich zur Ermittlung von Übertragungskoeffizienten: Linear/kraftbasiert und mittels Hauptkomponentenanalyse

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Introduction

Transfer Path Analysis describes how sound and vibration propagates through complex structures. The correct determination of transfer coefficients between sources and receivers is essential for a high quality analysis.

Conventional methods use artificial excitations (forces or volume velocities) to evaluate transfer functions. Therefore, they do not consider the influence of different load conditions on the transfer function behaviour of complex structures. In a second step, operational data (vibrations or sound pressures) are applied to the transfer functions to calculate the different path contributions.

In order to overcome these restrictions, transfer coefficients can be evaluated directly from operational data. Thus, the actual load conditions are taken into account and the quality of transfer characteristics is improved. The relation between simultaneously measured data of sources and receivers can be derived by statistical methods. Principal Component Analysis is used to separate the total signal into individual path contributions, while operating on airborne and structure-borne contributions simultaneously.

In this paper four different TPA approaches are compared for an analysis of the interior sound pressure of a car. All of them are taking crosstalk effects into account. The Matrix-Inversion method (MI) is subdivided into a case where the engine was removed for the impact test and a case where it was not. The same impact test was then applied to the Crosstalk Cancellation method (CTC) [1]. Since the CTC is based on principal component analysis (PCA) it can also be applied to operational data which is presented here as a fourth case.

Theoretical aspects

The Matrix Inversion uses FRFs ($H_{a/f}$) from an impact measurement to translate operational accelerations into operational forces. These forces are then multiplied with FRFs of the type $H_{p/f}$ to calculate the path contributions to the total interior sound.

$$P_{calc} = \sum_j P_j = \begin{bmatrix} p/f_j \end{bmatrix} \cdot \begin{bmatrix} F_{j,op} \end{bmatrix} = \begin{bmatrix} p/f_j \end{bmatrix} \cdot \begin{bmatrix} a_i/f_j \end{bmatrix}^{-1} \cdot \begin{bmatrix} A_{i,op} \end{bmatrix} \quad (1)$$

Keeping the engine mounted for the impact test of course produces different force signal in the impact hammer than in the mount. Thus in this case the calculated forces won't be equal the actual working forces under operation. On the other hand – at least formally – the hammer force can be cancelled in the formula when focusing on the sound contributions.

The main difference of the CTC is that it skips the normalization to the hammer forces. Thus this method is not based on FRFs but uses PCA to find statistically the relation H_i between observed signals on the source side and simultaneously observed signal on the receiver side.

$$P_{calc} = \sum_i P_i = \begin{bmatrix} A_{i,op} \end{bmatrix} \cdot \begin{bmatrix} H_i \end{bmatrix} = \begin{bmatrix} A_{i,op} \end{bmatrix} \cdot \begin{bmatrix} a_{j,i} \end{bmatrix}^{-1} \cdot \begin{bmatrix} p_j \end{bmatrix} \quad (2)$$

The main advantage is that this method is not limited to impact tests but can also be applied directly to operational data. This makes it even possible to investigate the different transfer behaviour for different load conditions (shown below) like e.g. for a runup and a rundown.

Test setup

The operational input measurement has been a WOT runup followed by a rundown and was carried out on a public road. Thus the main contributions can be expected to be engine noise, road noise and wind noise. For the comparison of the three impact methods only the transfer paths via the four mounts of the engine/gearbox compound have been used. The triaxial accelerometers have been attached on the carbody side. Hence for the following comparison only the structure borne engine sound in the range of the 2nd order (up to 200 Hz) shall be taken into account. The operational TPA however has been done including airborne channels and structure borne wheel contributions.

Results

The effect of removing active parts (engine) for the MI method is investigated for the total interior sound pressure as well as for the level of single path contributions. The same levels are used for the comparison of the MI and the CTC method. In the last section the enhanced possibilities of the CTC method are shown when being applied to operational data.

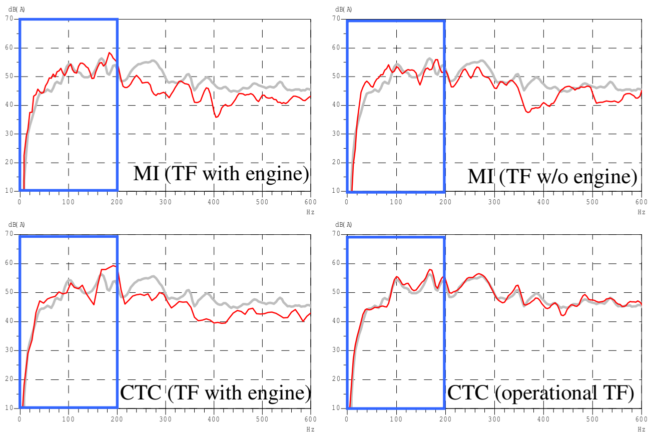

Figure 1: Sound pressure left driver ear. Square average of runup data. (gray: measured, red: calculated).

In the frequency range of the 2nd order the two MI results are very similar (fig.1, fig.2). So at least for this example it seems that it doesn't matter if the engine is removed for the impact test or not. Furthermore the CTC using the same impact data as the MI (with engine) shows a comparable result. In the 4th diagram the CTC algorithm is applied to operational data which include also airborne paths. The good fit indicates that all dominant paths are taken into account.

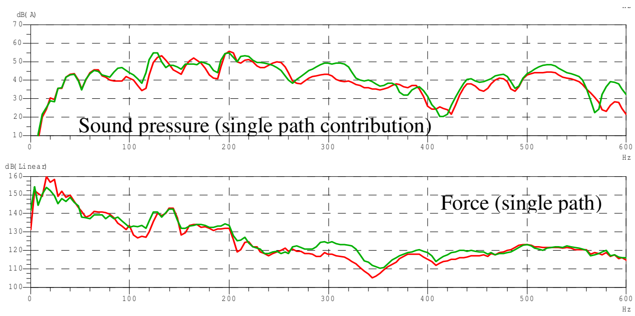

Figure 2: Single path comparison of the 2 Matrix-Inversion case. (red: with engine; green: engine removed) Averaged spectra.

As shown in figure 3 the similarity between the CTC and the MI (TF from impact test of the complete car) can be found even on a level of a single path.

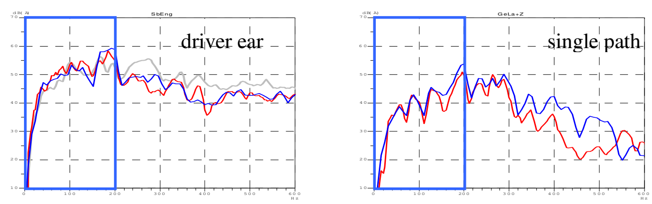

Figure 3: Comparison of MI (red) and Impact-CTC (blue). Averaged spectra.

Operational TPA is able to show that airborne (AB) and structure borne (SB) contributions have opposite phases in the frequency range of 160 to 200 Hz (fig.4) and thus partly cancel each other. This could explain why the impact results seem to overestimate the interior sound pressure in this range.

To verify the operational TPA method, one runup measurement is used to calculate transfer functions and another runup is being used for the sound pressure synthesis. Figure 5 shows the accurate reproduction of the car interior sound of the cross check.

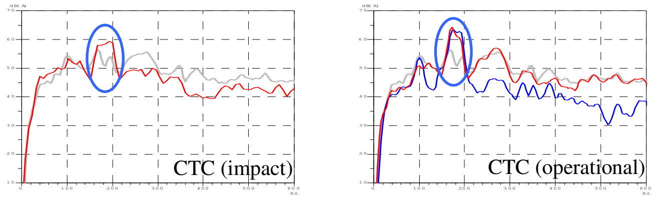

Figure 4: Left: CTC with impact (SB only). Right: CTC with operational data – SB (red) and AB (blue) contribution. Averaged spectra.

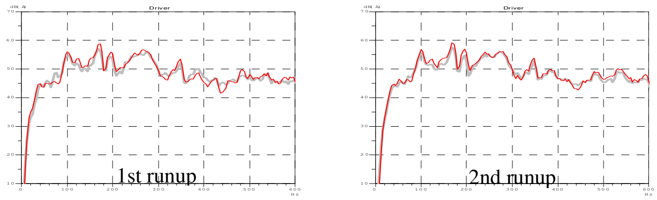

Figure 5: Operational TPA: Applying transfer functions taken from the 1st runup to a 2nd runup. Averaged spectra.

In order to show the influence of the load condition on the synthesis result, runup data is applied to rundown transfer functions and vice versa. The difference shown in diagrams 2 and 3 of figure 6 show, that the load condition of the transfer function measurement shall correspond to the load condition of the operational data.

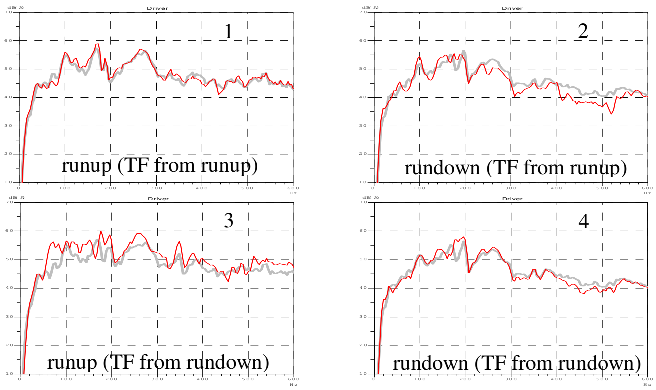

Figure 6: Operational TPA: Applying transfer functions taken from a runup to a rundown and vice versa.

Summary

The results based on impact test all showed similar results in the frequency range up to 200 Hz. Above this frequency other paths than the structure borne engine paths have to be taken into account. Operational TPA using Crosstalk Cancellation has been proven to be more accurate for sound synthesis under actual load conditions. Furthermore CTC is capable to produce accurate results from coherent structure borne and airborne sound contributions. Avoiding impact testing completely, operational TPA can reduce testing time significantly while enhancing simulation accuracy.

Literature

[1] Noumura, Yoshida, Honda R&D: Method of transfer path analysis for vehicle interior sound with no excitation experiment. FISITA (2006), F2006D183