Compensation possibilities of the omission of vehicle stages during the vehicle development process using specific measuring and simulation tools, with the BTPA (Binaural Transfer Path Analysis) as an example

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Introduction

With the specific use of measuring and simulation tools in the vehicle development shortened development times became possible. This is done via transmission of realizations from the development process of the predecessor model and/or from realizations of parallel running development processes of related model ranges.

On the basis of the BTPA (Binaural Transfer Path Analysis) of two related models, the OPEL Vectra and the OPEL Signum, it is exemplarily demonstrated, which data records and/or empirical values can be transferred in the future from one process to the other. The integration of FE simulation data and the use of target curves are tools, in order to replace not existing data records with sufficient reliability in the development process.

Fundamentals

Development process

In order to be able to react faster to the requirements of the market, a reduction of the vehicle development time is necessary. Thus also the time between the availability of the first prototypes and the beginning of production is reduced. In the course of the introduction of new development processes it is thought about omitting certain vehicle development stages.

Interior Noise

Employing hybrid methods like the BTPA of the company HEAD acoustics GmbH it can be examined, at which vehicle components a controlled influence on the interior noise can be exerted. For that reason the different transfer paths are measured from the source to the driver's ear. A following simulation makes it possible to fade out and/or change single paths in their transient characteristic and to listen to the sound result afterwards. In fig. 1 exemplarily the components of a structure-borne and of an airborne transfer path are depicted for a drive train. With 3 transfer functions a structure-borne transfer path will be sufficiently characterized from the source to the driver's ear.

This is in detail:

- the mount damping (relationship of acceleration at the engine a_{in} and acceleration at the body a_{out})
- the so-called apparent mass (relationship of applied force a_{out} into the body F_{in} and acceleration at the body a_{out})
- the acoustic transfer function or ATF (relationship of the sound pressure in the vehicle interior P_i and the applied force into the body F_{in})

In comparison the respective airborne sound path consists only of a single transfer function, the sound pressure relationship between sound-pressure level at driver's ear P_i and the sound-pressure level P_{anr} at the powertrain. During simulation of the interior noise with excitation data and the measured transfer functions a complex model of the transfer paths is developed, on basis of which it is possible to judge the cause of individual noise phenomena and analyze the contribution of individual paths at the entire interior noise. In the vehicle usually up to 50 transfer paths with up to 140 measuring channels are examined.

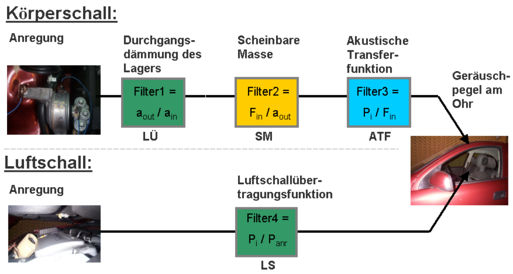

Fig. 1: Components of an airborne and an structure-borne transfer path

Characteristic properties of a noise path, like resonances and increased amplitudes in the engine orders, can be described very well on the basis of Campbell diagrams. In fig. 2 exemplary the partial sound pressure of an airborne sound path is depicted.

Implementation

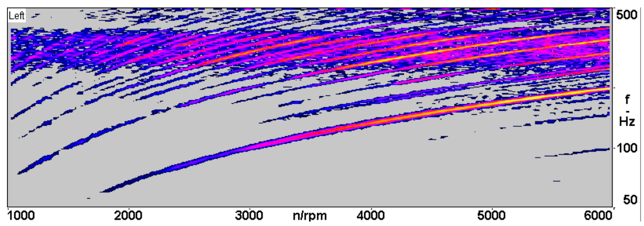

Fig. 2: partial sound pressure of an airborne sound path

BTPA at Vectra / Signum

Results of measurement

The execution of the BTPA at two related models of a platform, the OPEL Vectra and the OPEL Signum, gives a first reference, which elements of the BTPA are transferable. For that reason the individual transfer paths of the vehicle are specifically examined and compared.

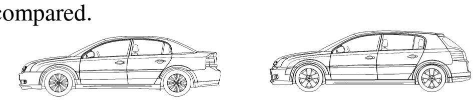

Fig. 3: Comparison of body form Vectra / Signum

The two vehicle models (see fig. 3) are almost identical up to the B-pillar of the structure of the body. Both vehicles are driven by a 1.8 liter gasoline engine and have the identical engine mounting concept. The influence of the partial different body concept on transfer functions and excitation functions was to be examined. The characteristics of the curve of mount damping, apparent mass and ATF of an engine mounting path of both vehicle models are almost identical. Mount damping and apparent mass are measures, which are to a large extent affected by the structure characteristics in the proximity of the mounting location. Therefore one could expect this result. But even the acoustic transfer functions, whose characteristic are affected by the different interior concept, show very good coincidence with these transfer paths (see fig. 4).

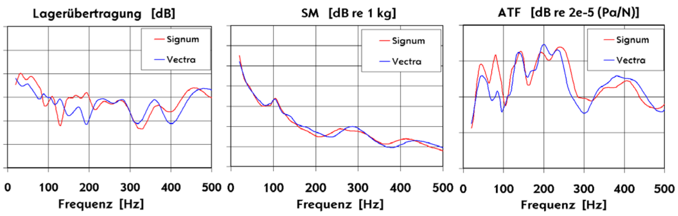

Fig. 4: Transfer functions of a structure-borne noise transfer path of an engine mount

In areas of very different body structures, like within the rear underbody, the transfer paths show relatively large differences, here demonstrated with the example of a rear exhaust hanger. The excitation functions i.e. operating accelerations at the engine mount and the sound pressure levels in the engine compartment with a selected

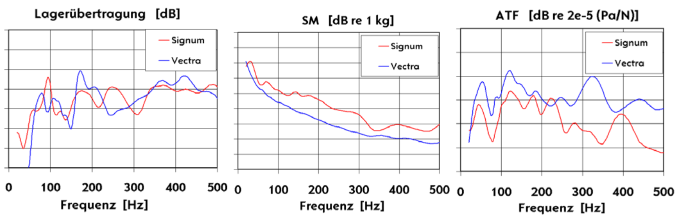

Fig. 5: Transfer of a structure-borne transfer path of a rear exhaust hanger

load case are similar due to identical engines of the vehicles. Depending on the emphasis of the investigation it has to be decided, which load case can be used for the description of a noise phenomenon. The investigation described above has shown, which elements of a BTPA model with related vehicle model ranges can be exchanged, in order to compensate disadvantages with the omission of development stages. Strongly different elements in the BTPA model must also be replaced in the development process by other information and experiences, in order to be able to meet the forecasts for a new model.

Hybrid formulation in vehicle development process

In order to enable a comprehensive simulation the necessary data can be built up from FE data, from target curves and/or from results of measurements of predecessor models.

a) Installation of mount stiffness into the BTPA model

Existing measured mount data make it easier to perform a BTPA simulation, since the mount transfer functions, which can be determined with difficulties only, can be calculated.
This is expressed by equation 1:

$$k_{dyn} = LU \bullet SM \bullet (2\pi f)^2 \qquad \text{Gl. 1}$$

k_{dyn}: mount stiffness
LU: mount damping
SM: apparent mass

A good estimation of the mount damping can be enabled by conversion of the equation to the mount transfer function LU, which can be used for the BTPA simulation.
As an example in fig. 6 the simulated interior noise levels of the 2nd engine order is represented with variation of the stiffness of an engine mounting. The interior noise level of a four-cylinder in-line engine is dominated by the 2nd engine order.
The BTPA Simulation shows that the engine mounting concerned a clear contribution in the speed range to approx. 2500 RPM.
By variation of the mount stiffness in the BTPA model the booming noise in this speed range could be improved clearly.

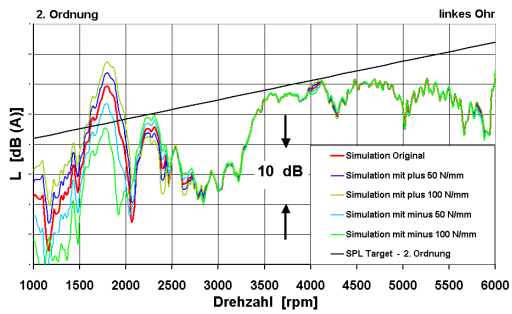

Fig. 6: Process of the 2nd Order with variation of the stiffness of an engine mount

b) Installation of target curves into the BTPA model

Another way to compensate missing vehicle data is to implement target curves. To a large extent these targets are defined in the vehicle specifications. The decrease of the portions of certain sound paths of the interior noise leads to a limitation of individual components within the BTPA model, e.g. apparent mass and ATF. Because often structural data are not available, target curves offer a good possibility to supplement data of the BTPA model.

c) Installation of FE data into the BTPA model

With a current vehicle project the data of the predecessor model are used in order to find optimization ranges and accomplish a weak-point analysis. So we are able to define plausible targets. The quality of a BTPA model is considerably improved by the combination of measured and FE data to a hybrid model. The transfer functions are interchangeable in both directions, test and FE simulation, dependent on the vehicle level of development. With the increasing quality of the FE models there will be a shift towards FE simulation.

Summary

As the market requires faster reactions on the product, development time has to be shortened. Therefore new structures must be introduced into vehicle development processes of Adam OPEL AG. Among others this means the replacement of certain vehicle development stages by simulation. A goal thereby must be the secured transmission of knowledge from the development process of the predecessor model and/or from knowledge of parallel running development processes of related model ranges to the actual development.

With the example of the BTPA it was shown which tools can help to put this idea into practice.

Targets for further improvements are:

Stronger coupling of the BTPA with the simulation methods, as well as still stronger integration and coupling of the BTPA procedure with the ESPI measuring method, which can visualize the oscillations of the sheet metal of the vehicle body.