Virtual Acoustic Prototyping for electrical steering systems

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The need for structure-borne sound prediction

In vehicles, the structure-borne sound contributions of many components are of interest. Relatively new kinds of components are electrically powered steering systems, which hence have to be looked at in detail. For ZF Lenksysteme GmbH, it is important to know the sound character of a certain steering system in a vehicle as early as possible in the development process. Therefore, the research project 'Virtual Acoustic Prototypes' (VAP) was initialized to develop a methodology to predict the structure-borne sound immission of steering systems in vehicles from experimental test rig data.

A prediction approach

Structure-borne sound prediction of complex systems often suffers from the lack of reliable measured and calculated data. For this reason a three step prediction process is used to predict the interior sound pressure in a vehicle. First, the passive data are checked on the same test rig, on which the characterization is performed (On Board Validation). Secondly, a prediction is conducted on another test rig to ensure the invariance of the characterization data to the first test rig and finally, the prediction of interior sound pressure in a vehicle is performed (see Figure 1).

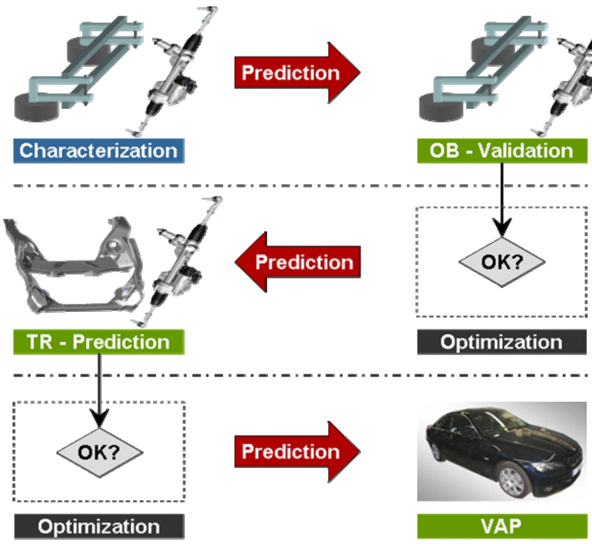

Figure 1: A three step prediction process – On Board Validation, Test Rig Prediction and Virtual Acoustic Prototyping

On Board Validation (OBV)

The OBV is to validate the passive measurement data (inverted in-situ mobility matrix). In the characterization process blocked forces are determined, according to the in-situ blocked force method [1]. Firstly the forces are provoked by an artificial activation of the source. Using an in-situ TPA method, a prediction of vibration is performed at the same test rig and regularization procedures are performed to optimize the inversion of the in-situ mobility matrix [2]. As soon as the in-situ impedance is validated, the source is operated in real terms. Time domain blocked forces are calculated by the convolution of the inverse fourier transformed impedance frequency response functions and the measured time domain velocities.

Test Rig Prediction

The test rig prediction is needed to validate the time domain blocked forces from the OBV process. Usually the target structure is not available for the purpose of validation and therefore the blocked forces have to be confirmed before the actual VAP prediction. The source is assembled to another, different, test rig and activated. The time domain in-situ mobility matrix of this test rig and the time domain blocked forces from the OBV process are used to predict vibrations on this second structure. Once more the measured velocities are compared to predicted ones and hence the wanted blocked forces can be verified.

The Virtual Acoustic Prototype

A well validated set of blocked forces can now be used to predict the interior sound pressure via combination with vehicle transfer functions [2]. This enables the prediction of sound from operational measurements performed on a test rig, if vehicle data are available, either from simulation or measurement. Furthermore the steering systems can artificially be implemented in several vehicles in early development phases.

Experimental results

Firstly, a measured sound pressure level in a vehicle is shown in Figure 2. The steering system is driven with a certain steering velocity. Several steering manoeuvres from the left to the right end lock can be seen in frequency dependent sound pressure levels over time.

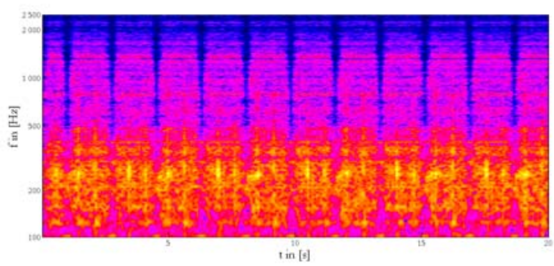

Figure 2: Measured interior sound pressure level (A-weighted) of the vehicle during a fast steering manoeuvre, with bright colours indicating high levels

The predicted sound pressure level from the VAP is shown in Figure 3.

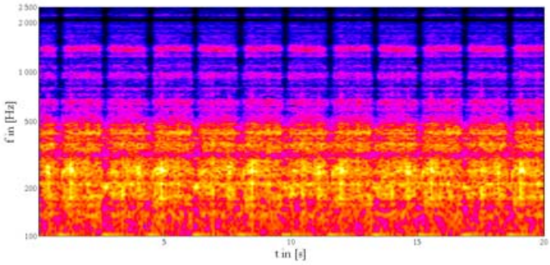

Figure 3: Predicted interior sound pressure level (A-weighted) of the vehicle-steering system assembly

In both plots the characteristics of an operating steering system can be seen. The single steering blocks and the end lock behaviour are apparent in the prediction, as it is in the measurement. The frequency region between 200 Hz and 300 Hz contributes most to the interior sound pressure, whereas above 500 Hz certain frequency bands are almost covered by background noise. Generally the calculation slightly over-predicts, especially between 100 Hz and 200 Hz. This is due to the measured mobilities, caused by the poor signal to noise ratio of the used structures, which are hardly vibrating in this frequency range**.** The interior sound pressure level can be predicted with good quality from operational test rig data, using the in-situ blocked force method and the three step prediction approach.

A psychoacoustic comparison of prediction and measurement

Beside the pure level comparison of measurement and prediction, the human perception of the signals is an important factor for the success of a VAP. Therefore a tool is chosen to be able to compare the perception of humans of the two sound signals. The Relative Approach [3] turned out to map very well with subjective evaluations of steering systems. For this reason a relative approach analysis is carried out for both signals.

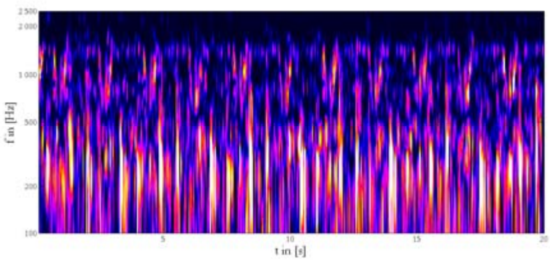

Figure 4: The Relative Approach analysis of the measurement as an objective psychoacoustic measure

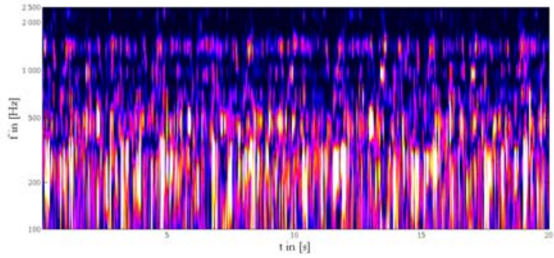

Figure 5: The Relative Approach analysis of the predicted interior vehicle sound signal

Both psycho acoustic analyses show similar patterns and are in the same range of magnitude (0 – 3 cp). In the low frequency range, up to 500 Hz, the perception is stronger than in the high frequency range. Especially at the end lock positions, high values can be seen over a wide frequency range. During the constant steering speed, certain frequency ranges are highlighted in both plots (around 1400 Hz). The agreement of both analyses is good for steady state excitation as well as for the included impulsive sound phenomena. The psychoacoustic evaluation therefore strengthens the interior sound pressure prediction using a VAP approach and the proposed three step procedure.

Summary

In brief, a process is introduced to perform structure-borne sound prediction, based on the in-situ blocked force theory, presented in [1, 2]. The proposed approach focuses on the validation of the passive measurement data and the calculated blocked forces before the VAP prediction is performed. The approach is verified via comparison of measured and predicted sound pressure in a vehicle. Furthermore, the Relative Approach, a psychoacoustic analysis, is carried out showing the similarity of both sound signals to allow for the evaluation of human perception.

Acknowledgements

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Literature

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