Contribution Analysis of Simulated Pass-by Data using Operational Transfer Path Analysis

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ABSTRACT

As the exterior noise emitted by a vehicle is getting more and more attention, simulated pass-by measurements become more important. This well established method provides information about the total noise emitted by the vehicle. For a vehicle manufacturer it is not only interesting to know about the total noise but also to know how this total exterior noise is composed of different contributions, such as for example the contribution of the engine, the intake or exhaust system. Transfer path analysis (TPA) provides a separation of these contributions for each of the pass-by microphones alongside the track. Presented is a method for fast and efficient determination of the contributions of multiple sources using operational transfer path analysis (OTPA). The calculation of the transfer characteristics between the reference measurement points on the vehicle and the corresponding response points of both microphone lines are carried out while operation of the vehicle. As result of the contribution analysis from operational transfer path analysis, the characteristic noise level as function of the covered distance is displayed for all individual sound sources, thus providing in depth information for sound quality engineering.

1. Introduction

With simulated pass-by measurements on a chassis dynamometer the total exterior noise of a vehicle is analyzed at dedicated positions alongside a track using lines of microphones on each side of the vehicle. Each microphone pair corresponds to one position of the car on a real pass-by track. By interpolating the sound pressure level of the microphones to equidistant track positions, the real pass-by condition is simulated. As result of the simulated pass-by analysis the total noise level of a vehicle is displayed as function of the covered distance.

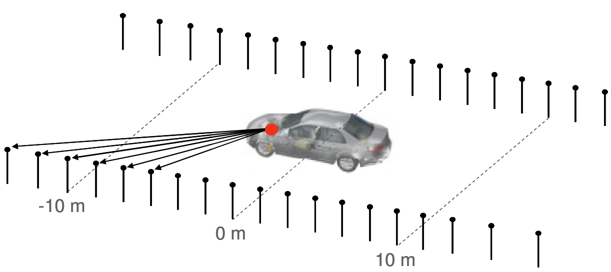

Fig 1: Microphone setup for simulated pass-by measurements

The simulated pass-by analysis is a well established method to determine the total exterior noise emitted by a moving vehicle. For the vehicle development it is not only interesting to have the information about the total noise level, but also to know how this total noise is composed of different contributions, such as dominant sources like engine, intake or exhaust system. To extract this information, the different sound sources of a vehicle have to be measured at least. Therefore, an Operational Transfer Path Analysis (OTPA) can be executed for each of the simulated pass-by microphones.

As result of such a contribution analysis of simulated pass-by data with operational TPA, the total exterior noise is separated into single contributions, such as for example the contribution of the intake system as a function of the covered pass-by distance.

2. Contribution Analysis of simulated pass-by data using OTPA

2.1 Operational Transfer Path Analysis

Operational TPA (OTPA) has been developed and tested on vehicles [1], [2], [3] during the last 5 years. It is proved to be an efficient and fast method since only measurements of operational data are required to identify critical sound and vibration paths as well as source contributions.

OTPA is based on a signal processing method to determine linearized Transfer Functions (TF) between selected reference (source) and response (receiver) points from a multichannel measurement. Contributions of a source path to interested response points can be identified by using these calculated Transfer Functions in a Transfer Path Synthesis (TPS).

With this method the reference and response signals can be obtained from one single measurement during operation of the vehicle. The relation between reference and response signals can be derived by statistical methods. Principal Component Analysis (PCA) within the Crosstalk Cancelation (CTC) is used to separate the total signal into individual path contributions, while operating on airborne- and structure-borne contributions simultaneously.

Consider an arbitrary, linear system with a number of reference and response points, the relationship between these points is represented as

$$[H(\omega)]\{x(\omega)\} = \{y(\omega)\} \tag{1}$$

The transfer function matrix $[H(\omega)]$ is describing the transfer characteristic between the vector of response signal $\{y(\omega)\}$ and the vector of reference signals $\{x(\omega)\}$. Usually accelerations $a(\omega)$, sound pressures $p(\omega)$ or forces $f(\omega)$ are used for the OTPA. The engineer is not restricted to use forces as excitations, but can use accelerations or sound pressures, even those are responses from a physical point of view.

The OTPA method determines all elements of the TF matrix from only one measurement where all excitations and responses are present. Transposing of Equation (1) results in:

$$\begin{bmatrix} x^{(1)} & \dots & x^{(m)} \end{bmatrix} \begin{pmatrix} H_{11} & \cdots & H_{n1} \\ \vdots & \ddots & \vdots \\ H_{1m} & \cdots & H_{nm} \end{pmatrix} = \begin{bmatrix} y^{(1)} & \dots & y^{(n)} \end{bmatrix} \tag{2}$$

The numbers of reference and response points are denoted by *m* and *n*. Taking the transpose does not allow the determination of the TF elements, as the linear system of equations is under-determined. However, during an operational measurement of a vehicle with varying running conditions, a number of synchronized multichannel measurement blocks are acquired. As excitations are changing e.g. during a run-up, the resulting matrix rows are typically linear independent. Assuming linear and constant TFs, Equation (2) can be extended to all measurement blocks r, as

$$\begin{pmatrix} x_1^{(1)} & \cdots & x_1^{(m)} \\ \vdots & \ddots & \vdots \\ x_r^{(1)} & \cdots & x_r^{(m)} \end{pmatrix} \begin{pmatrix} H_{11} & \cdots & H_{n1} \\ \vdots & \ddots & \vdots \\ H_{1m} & \cdots & H_{nm} \end{pmatrix} = \begin{pmatrix} y_1^{(1)} & \cdots & y_1^{(n)} \\ \vdots & \ddots & \vdots \\ y_r^{(1)} & \cdots & y_r^{(n)} \end{pmatrix} \tag{3}$$

The TF matrix ***H*** is now over-determined and the method of singular value decomposition (SVD) is used to overcome numerical problems in the inversion of the matrix ***X***. Furthermore, as noise and other external interferences are represented by smaller singular values, crosstalk and noise can be cancelled from Transfer Functions (TF).

2.2 Contribution Analysis of simulated pass-by data

Originally this OTPA method was developed for an efficient analysis of the interior cabin noise of vehicles. For the determination of the transfer functions typically several run-up and run-down measurements are acquired. This increases the diversity of the excitation conditions and leads to better numerical stability.

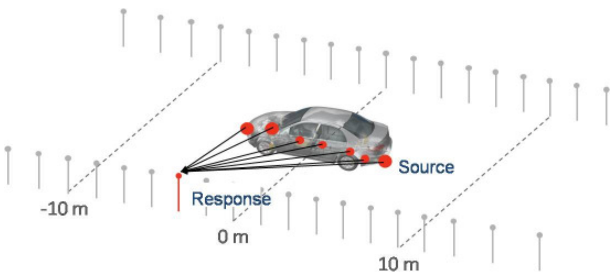

Fig 2: Operational TPA at one response microphone

For simulated pass-by measurements two parallel microphone lines on each side of the vehicle are used as response points. To separate the total exterior noise into single contributions, OTPA is being applied for an arbitrary number of sound sources to each simulated pass-by microphone.

Typical sensor positions representing dominant sound sources are located for example at the vehicle engine, the exhaust and intake system. Usually microphones are used to measure the noise emitted by the different sound sources. Often the sound field nearby one source is not precisely representing this source only, but is partly influenced by other sources too. Thus a clear separation using microphones might be difficult in some cases. This problem could be overcome if accelerometers are applied in a way that the measured velocities are well describing the emitted sound of the source. All the sub-contributions of the different accelerometers (describing surface patches of the source) are added up to the whole source contribution. In the same way, several microphones can be applied to describe for example the sound emitted in the engine compartment.

An OTPA is conducted for each of the pass-by microphones on both sides of the vehicle to determine the TF to each of the reference measurement points on the vehicle. Thus allowing a separation of all *m* response signals to *n* contributions. The standard simulated pass-by analysis shows the total emitted noise of the vehicle for each pass-by position along the covered track, whereas the output of the conducted contribution analysis is describing the individual sound sources. The result of the contribution analysis displays the sound pressure level of each sound source as function of the covered distance (see Fig. 3).

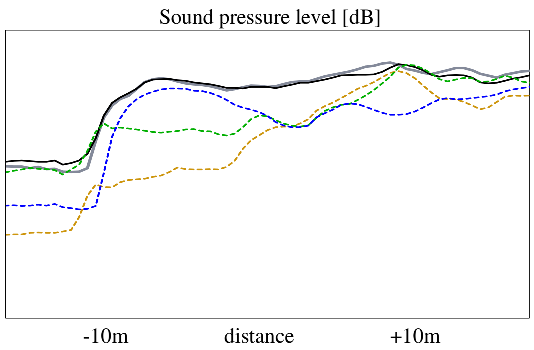

Fig 3: Example of a contribution analysis. Displayed are the sound pressure levels over covered distance of the original measurement (grey), three contributions (intake, engine, exhaust - dashed) and the sum of the contributions (black)

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3. Summary

Traditionally the masking method is used to analyze the contributions in simulated pass-by. This method requires high efforts for temporary modifications of the vehicle to eliminate single sources step by step.

With operational transfer path analysis (OTPA) a highly efficient and accurate alternative is available reducing the time for the contribution analysis of simulated pass-by data significantly.

Transfer functions between the reference points on the vehicle and each response point of both simulated pass-by microphone lines are calculated during operation of the vehicle (e.g. run-up and run-down measurements). These transfer functions are applied to a simulated pass-by measurement to separate the total exterior noise into individual contributions of different sound sources, thus providing precise information for sound quality engineering.

References

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