Binaural Auralization of Vibrating Surfaces – Laser Scanning Vibrometry Combined with Binaural Transfer Path Analysis

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Introduction

Acoustical measurements are traditionally performed using conventional microphones for airborne noise problems and accelerometers for structure-borne noise and vibration analysis applications.

When dealing with acoustical investigations of extended sound sources like panels of automotive vehicles it can be rather time consuming when using conventional accelerometers. In the past years an alternative measurement system, the laser scanning vibrometry, has become more and more established in industry and research leading to much faster and more precise measurements and to more comfort for the user than before. A further advantage is the fact that laser vibrometry is a non contact measurement method and no extra weight is put onto the structure. Otherwise the acoustical properties of the object could change.

These advantages combined with the ease of getting appealing results have led to the application of laser vibrometry to airborne noise as well. Visualized vibrational motions are used to predict possible noise problems by addressing vibrations directly to emitted sounds. Then, possible acoustically weak areas of the structure are identified providing the basis for recommendations for acoustical countermeasures.

Even though this procedure seems to be quick and easy it has several draw backs: First of all the way the sound takes from the noise source (panel) to the receiver (human ear) is an important element that has not been accounted so far. In order to do so airborne noise transfer functions have to be additionally included in the analysis. Secondly, the radiation factor has been neglected. Especially low frequency vibrations generally do have a much smaller radiation factor than high frequency vibrations and should therefore be weighted differently. Also the perception of sound by the human being and psychoacoustic aspects cannot be assessed properly. A prerequisite would be to investigate the structure under an appropriate running condition. Concerning vehicles one might think of a run up or a test drive on the road. Unfortunately, this is not applicable for laser scanning vibrometry since the laser can spot only one single point at a time implying that necessary phase information between all measuring points would be lost. Hence, triggered deterministic excitations via shaker etc. are usually used to enable for correct phase relationships.

Outline of Idea

However, laser scanning vibrometry can be successfully used for the determination of transfer functions. When looking at the conventional transfer path analysis where transfer functions are used as filters for measured time signals one might think of applying this procedure to laser measurements as well. Time data which have been gained for example from accelerometers at force input positions of vehicles operating under running conditions might be linked to transfer functions determined by laser scanning vibrometry. Further inclusion of room acoustic transfer functions would then allow to extend the pure vibration analysis of laser vibrometry to a full acoustical analysis. Transfer paths might additionally be determined with respect to the test person's ears. This procedure is called binaural transfer path analysis BTPA [1] and serves for realistic audible stereo sound files.

Test on Model Structure

A model test structure has been built up to test the concept of laser scanning vibrometry connected with binaural transfer path analysis. The model consists of a steel frame with aluminium plates of various sizes being directly attached onto it. Two shakers introduce the force input into the structure (Figure 1).

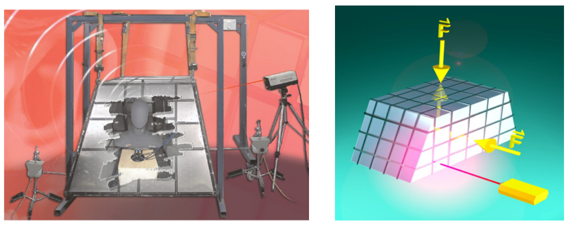

Figure 1: Model structure for test measurements

Firstly, the laser has been used to measure the structure-borne transfer functions H_S between the force input F at the shaker positions and the velocity response v of the surfaces:

$$H_S = \frac{v}{F} \qquad (1)$$

This has been done for all surfaces and for both shaker positions separately.

Secondly, in order to predict the sound for a test person being inside the model the corresponding airborne noise transfer functions inside the model have been measured. This has been done making use of the reciprocity principle [2]. The appropriate sound source for this type of measurements is a binaural sound source that has been described previously [3]. Using conventional pressure microphones the transfer functions H_A were measured for the left and the right ear, respectively. The sensors were placed on the panel corresponding to the positions of the previous laser measurement. The volume velocity Q of the sound source has then been related to the measured sound pressure P:

$$H_A = \frac{P}{Q} \tag{2}$$

Using the structure-borne and the airborne noise transfer functions as filters it is principally possible to predict the sound pressure contribution $P_i(t)$ of each panel i to the total sound pressure at the test person's ears for any arbitrary time signals $F(t)$ being applied to the shakers (A_i represents the effective surface of a measuring point i):

$$P_i(t) = F(t) * \left[A_i \cdot H_{A,i} \cdot H_{S,i}\right] \tag{3}$$

Since the procedure works binaurally the output file is a stereo file that makes it possible to spatially localize the individual panel contributions.

Test on Vehicle

A first test measurement on a vehicle has been performed. Door and fender have been scanned with a laser vibrometer under different excitation conditions.

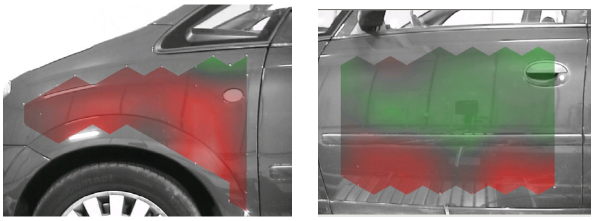

Figure 2: Mean surface velocity for engine excitation

Figure 2 shows the average surface velocity when excited by engine in idle mode. It is obvious that if no airborne transfer functions are taken into account the fender seems to be an acoustically critical surface. In contrast, Figure 3 displays the mean velocity distribution when reciprocally excited by airborne noise at the driver's position.

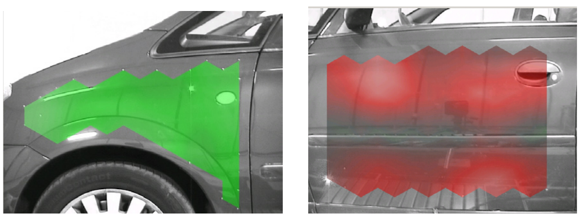

Figure 3: Mean surface velocity for airborne excitation

Due to this result it is evident that the fender is not a critical area since even though strongly excited by the engine the sound paths from this area to the interior at the driver's position do not play a significant role. Figure 4 presents the final result where the engine excitation result has been numerically weighted with the determined airborne transfer functions. As can be seen in this example the bottom of the door seems to play the mayor role.

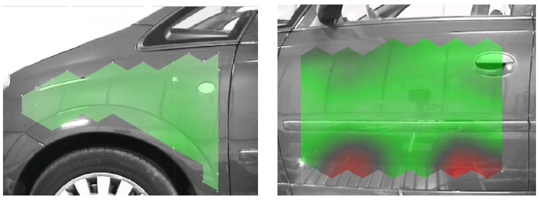

Figure 4: Model structure for test measurements

Conclusions and Outlook

This procedure allows for direct identification and representation of surface areas which are of acoustical relevance since it includes the airborne transfer functions of the interior vehicle.

Further measurements have been already performed on a door panel investigating the vibrations in the time domain. For the matter of ease a sweep has been chosen for excitation instead of a real run up. Unfortunately, the visualization of the discrete swinging behavior of the door panel in the time domain could not be analyzed easily due to the rapid motion and useful information was not directly accessible. But when an appropriate analysis to the data has been applied, like sound pressure level versus time, acoustical critical surface areas as a function of time or engine speed respectively became transparent. This procedure enables for adequate assessment of acoustically relevant surface areas when excited under realistic running conditions. Hearing related evaluation analysis can be applied as well. Additionally, filtering procedures can be used to predict and visualize the estimated acoustical effect of insulation material being applied to the vibrating surface as a function of running condition.

Further investigations and validation experiments on vehicles under realistic running conditions are in preparation.

References

[1] K. Genuit, J. Poggenburg: The Design of Vehicle Interior Noise using Binaural Transfer Path Analysis. SAE '99 (1999)

[2] F. J. Fahy: The Vibro-Acoustic Reciprocity Principle and Applications to Noise Control. Acustica **81** (1995), 544-558

[3] P. Sellerbeck, M. Klemenz, R. Sottek: Ein binauraler Schallsender zur reziproken Transferpfadanalyse. DAGA (2003), 290-291