Binaural Panel Noise Contribution Analysis
An Alternative to the Conventional Window Method

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Introduction

When performing measurements to evaluate the acoustical influence of vehicle interior panels one is often confronted with a number of various difficulties.

The interior sound of a car is the sum of diverse contributions of different sound sources with individual sound paths. Typical sound sources are tire noise, engine noise as well as transmission noise and wind noise. Their transmission paths towards the listener's ear inside the vehicle are for example acoustical bridges for structure-borne noise, firewall, pillar, etc. The noise that finally enters the passenger compartment finds its way through panel areas like windows, roof, side walls and also the floor. Each panel contributes in a specific way to the overall interior sound and is therefore responsible for the acoustical comfort for driver and passenger.

When trying to measure the acoustical influence one might think of using intensity microphones for the determination of radiated sound power of the panels under investigation. Typically, two difficulties have to overcome. Firstly, conventional pp (pressure-pressure) intensity microphones are not really suitable when used in reactive sound fields or at low frequencies. PI index limitations or the necessary exchanges of spacer distances for special frequency regions are making measurements being a challenge. This applies to a majority of application scenarios inside vehicles where often sound fields are turbulent and interesting frequencies are in the lower range. Secondly, since intensity is a quantity which is related to the acoustical energy or the radiated sound power of a sound source it is principally not possible to use the gained information for the reconstruction of the sound field. Thus a further auralization is not possible. This can be understood if one realizes that sound intensity is the complex product of pressure and velocity and therefore phase information of pressure will be lost during multiplication.

Another approach is the conventional "Window Method" sometimes also called "Subtractive Method" which is common and often used. Using this method makes it necessary to encapsulate the whole interior of the vehicle with acoustic insulation material. Due to the mass law that relates insulation behavior of applied mass to the frequency these insulation packages have to be rather heavy depending on the frequency range under investigation. The tremendous mass input into the structure alters the acoustical behavior in two ways. First of all the structure itself is changed having a certain impact on the structure-borne noise. Secondly, the absorption characteristic of the vehicle is totally changed.

A further fundamental draw back of the conventional "Window Method" is the fact that not all relevant running conditions of the vehicle can be investigated. Measurements are limited to indoor measurements on a chassis dynamometer. Road measurements are generally too risky for the driver or simply not possible at all.

New Procedure

In view of the mentioned difficulties that arise when using the conventional "Window Method" a new methodology has been invented. By using a special sensor array it is possible to determine the acoustical contribution of each panel to the sound pressure at an arbitrary position of a test person inside the vehicle. The analysis is performed binaurally which serves for adequate auralization.

The key element of the new procedure is the use of a special type of sensor that allows for directly measuring the airborne noise particle velocity in a distinct point in space [1]. This cannot be accomplished by conventional particle velocity sensors since in that case the quantity has to be deduced from measurements made with two pressure microphones kept at a certain distance to each other leading to difficulties in turbulent sound fields.

Once the sensor array is applied to the vehicle panel under investigation the measurement can be performed under arbitrary running conditions of the vehicle. Even test drives on the road are feasible which might be of particular interest for investigations where the incorporation of wind noise or tire noise for example for wet or rough road conditions is important.

After finishing the measurements a second step follows: The airborne noise transfer functions from the panel to the listener's ear (e.g. driver) have to be determined. This is necessary in order to make the panel contribution audible. The transfer functions can either be measured directly which leads to an enormous experimental effort or can be determined making use of the reciprocity principle [2]. A special sound source for reciprocity measurements has to be placed at the position of the test person. Since the reciprocity principle requires the same acoustical characteristics of receiver (test person) and sender (sound source) the used sound source has to have the shape of a human head with two speakers instead of ears. This type of binaural sound source has been described previously [3].

Once the airborne noise transfer functions between sound source and sensors have been determined it is possible to use these data as filters and to link them with the measured time data. The resulting sound files represent the auralization of the specific panels under interest. Since the transfer functions have been separately measured for the left and the right ear the auralization is quasi realistic and allows for acoustical localization.

Verification

This new method has been successfully tested on several vehicles. For verification purposes the complete interior surface of a vehicle has been tested. The array has been applied to 7 surfaces: front roof (including front window), rear roof (including rear window), left side, right side, front floor, rear floor and cockpit. The measurements have been performed on a chassis dynamometer, the vehicle running condition was 3rd gear run up from 50 km/h up to 120 km/h followed by a coast down.

The calculated total sum of the panel contributions to the left ear has been compared for validation purposes to the sound pressure level measured by a binaural head microphone. The result can be seen in figure 2. Measurement (green curve) and simulation (red curve) are in reasonable agreement with each other. The other curves represent single surface contributions.

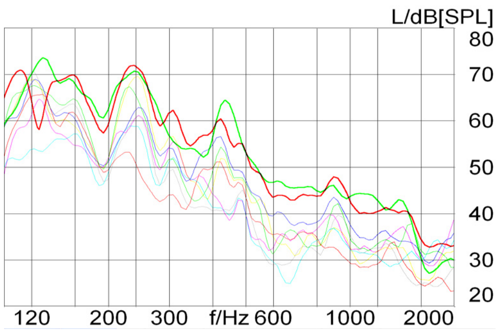

Figure 1: Sum of all panel contributions (red) compared to measurement (green), single surface contributions (other)

In order to verify whether cross talk between adjacent sensors might play a significant role or not a separate measurement has been performed. For single sensor positions the sound insulation of the vehicle has been locally enhanced by application of insulation material. The effect of this measure should have an influence on the sensor directly involved (sensor A) while an adjacent sensor (B) should not show any effect. Otherwise cross talk would be of importance. As figure 3 shows there is no major effect on sensor B in contrast to sensor A. This implies that cross talk does not play a significant role.

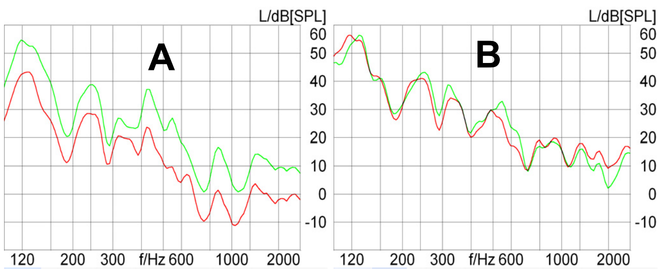

Figure 3: Exclusion of crosstalk between adjacent sensors (left: effect of vehicle insulation measure on sensor A; right: no effect on sensor B)

These findings make it possible to compare the acoustical contributions of the surfaces with each other and to rank their acoustical importance. Figure 4 shows that the rear floor exhibits the biggest contribution (upper left diagram).

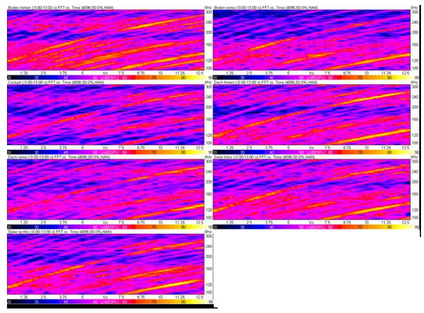

Figure 4: Comparison of all contributing surfaces

Even a detailed mapping of individual surfaces is possible. Figure 5 shows the rear floor in detail.

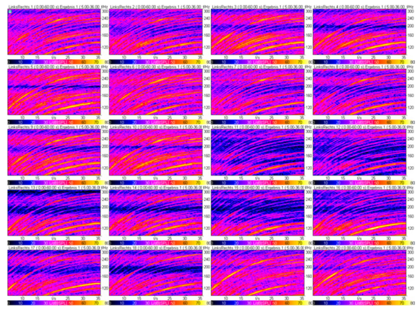

Figure 5: Mapping of a single surface (rear floor)

Conclusions

The new methodology is considered to be an alternative to the common “Window Method”. The following features are advantageous:

- **Auralization of individual panel contributions**
- **No insulation material needed**
- **Acoustic of vehicle remains unchanged**
- **Arbitrary running conditions accessible (e.g. driving on road)**

The method allows for a direct identification of acoustically weak areas and thus serves the acoustical engineer for finding the appropriate positions where countermeasures should be most effective.

References

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