Virtual Binaural Auralisation of Vehicle Interior Sounds

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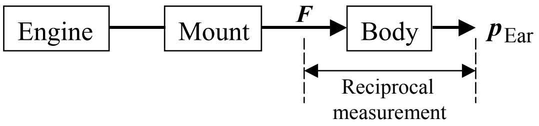
Introduction

In order to optimize the quality of vehicle interior sounds already at an early stage of development, two methods called "BTPA" and "BTPS" (Binaural Transfer Path Analysis and Binaural Transfer Path Synthesis) have been developed [1]. Since these methods involve the auralisation of the contribution of each individual sound path, all corresponding transfer functions must be measured separately. The methods distinguish between structure-borne and airborne sound paths.

Structure-borne noise path:



Airborne noise path:

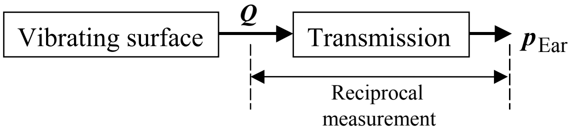


Figure 1: Transfer functions used for BTPA

The transmission of airborne and structure-borne sounds to the driver's ears is measured reciprocally using a recently developed binaural volume velocity transducer on the driver's seat (figure 2) [2] as well as microphones or accelerometers at the noise source positions (figure 3).

Figure 2: Binaural sound source and additional subwoofer

For comparison figure 4 illustrates the direct measurement procedure used in the past. The determination of binaural vibro-acoustical transfer functions requires the excitation with a calibrated impact hammer at various positions of interest as well as the simultaneous recording with an artificial head in the vehicle interior. The excitation in the engine compartment at the body side of the engine mounts is sometimes difficult because of space limitations. The airborne transfer functions are measured by relating the artificial head recordings with the microphone signal in the vicinity of the loudspeaker used for excitation.

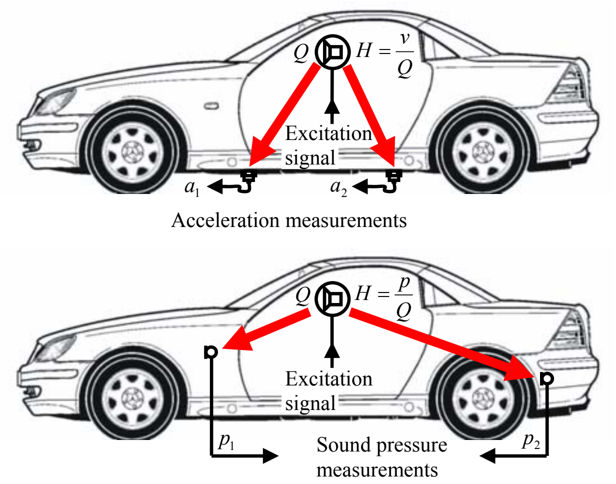


Figure 3: Reciprocal measurements

The advantages of taking reciprocal measurements of acoustic transfer functions are evident: First, less space is required for sensors than for sources. Thus the measurement positions can be chosen almost without restriction leading to a higher accuracy. Second, significant time is saved, since all paths can be measured simultaneously. First applications in vehicles have been promising.

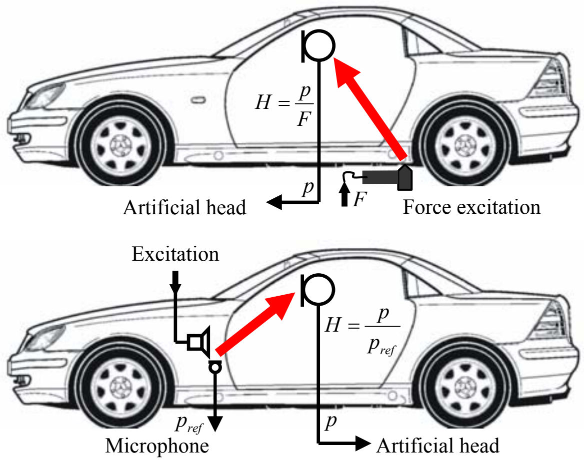


Figure 4: Direct measurements

Advanced Techniques

Further improvements of the described methodology can be achieved by replacing intricate measurements by simulations using computer models. The goal of these efforts is to divide each transfer path into partial structures. If only one component is modified, the simulation only needs to be performed for the modified substructure rather than for the entire transfer path. Regarding the structure-borne sound transmission in vehicles from engine to chassis easy-to-use models can be found with the help of the four-pole theory.

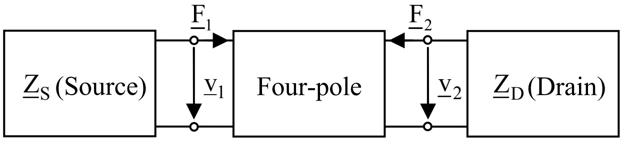


Figure 5: Subsystem (e.g. engine mount) described by four-pole parameters (2x2 matrix for each frequency of interest) relating force and velocity at output and input terminals (e.g. body resp. engine side), $\underline{Z}_S$ and $\underline{Z}_D$ are the mechanical impedances of the connected subsystems.

Four-poles are approximated by electromechanical circuits, in order to analyze the influence of the subsystem on the complete vehicle model.

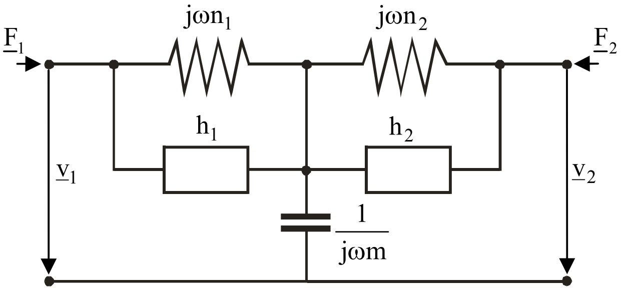


Figure 6: Equivalent network of an engine mount (m: mass, n resilience, h: friction admittance)

The parameters m, n and h may result from curve fitting algorithms based on the complete set of four-pole matrices (frequency dependent).

The next figure shows a principle measurement set-up for the determination of the four-pole parameters using the condition $\underline{v}_2 \approx 0$.

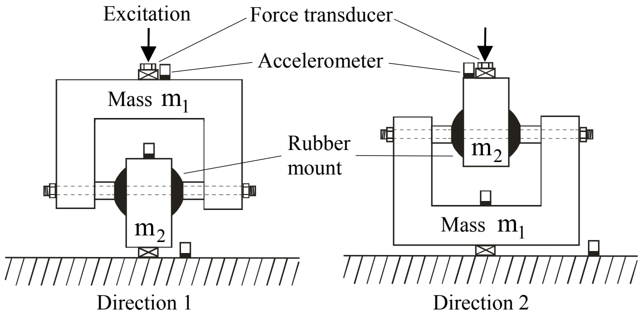


Figure 7: Measurements of four-pole parameters of an engine mount

The measurements of force and velocity at both terminals have to be carried out in two directions in order to calculate the whole four-pole matrices. The velocity at the output terminals is used to check the assumption of infinite terminating impedance. As it can be seen in figure 7 the measured system consists of three subsystems in a serial connection: mass 1 – engine mount – mass 2. The coupling masses are needed to adapt the mount to the test rig. The four-pole matrices of the masses are known, thus their influence can be considered to calculate the four-pole parameters of the engine mount of interest by applying simple matrix operations.

Application Example

As mentioned before, the application of the four-pole theory is useful regarding the modification of subsystems. In the following the influence of an inserted mass in the centre of a rubber mount is studied. Hereby a symmetrical partitioning of the mount is assumed. The matrix $\underline{A}$ describes the measured four-pole of the original mount.

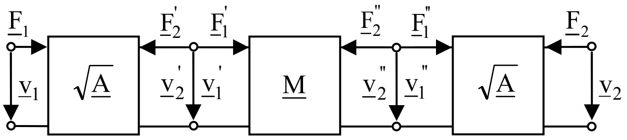


Figure 8: Insertion of an additional mass

The matrix of the serial connection of the systems shown is the product of all three matrices. Under original condition the inner matrix M equals the identity matrix and therefore no changes occur.

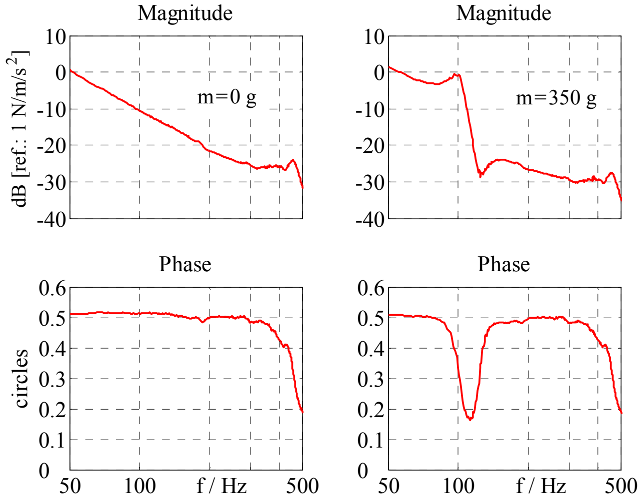


Figure 9: Change of effective engine mount transfer function (force/acceleration) due to the insertion of an additional mass (m=350g), using measured four-pole parameters of an engine mount and apparent mass of a vehicle. The result is higher damping at higher frequencies and a phase change around 100 – 150 Hz that can be used to achieve less interior noise level because of destructive superposition of single transfer paths.

Outlook

Further improvements of BTPA/BPTS are possible making use of numerical simulations of subsystems (FEM) to reduce the measurement efforts for the determination of the four-pole parameters. Modeling of sound sources and the sound field in the engine compartment is under development using boundary element calculations and measured data.

References

[1] K. Genuit and W. Bray, Prediction of Sound and Vibration in a Virtual Automobile, *Sound and Vibration, July 2002.*

[2] R. Sottek, P. Sellerbeck and M. Klemenz, “An Artificial Head which Speaks from its Ears: Investigations on Reciprocal Transfer Path Analysis in Vehicles, Using a Binaural Sound Source”, in *Proceedings of SAE ‘03,* Traverse City, 2003