APPLICATION NOTE

About this document

Content

This document is the fourth of five application notes on transfer path analysis (TPA). The first chapter contains practical information on sensor technology. The subsequent chapters provide information on how to perform transfer function measurements and operational measurements. The last chapter lists potential sources of error.

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Target group

The following text is primarily intended for (potential) ArtemiS SUITE users who want to familiarize themselves with the basics of TPA.

Questions?

Do you have any questions? Your feedback is appreciated!
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For technical questions on our products: SVP-Support@head-acoustics.com

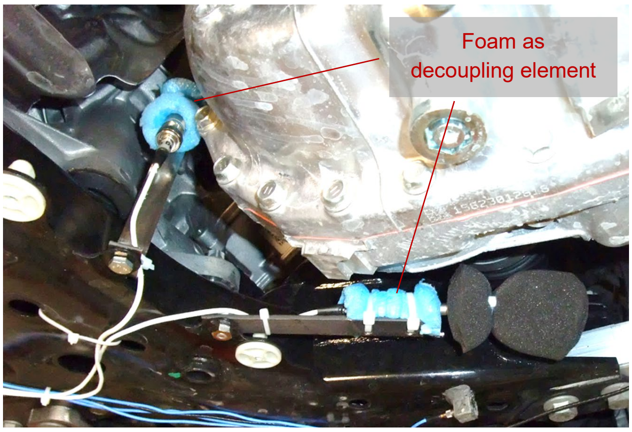
Transfer path analysis – Practical advice

1. Sensor technology

Microphones

Microphone mounting

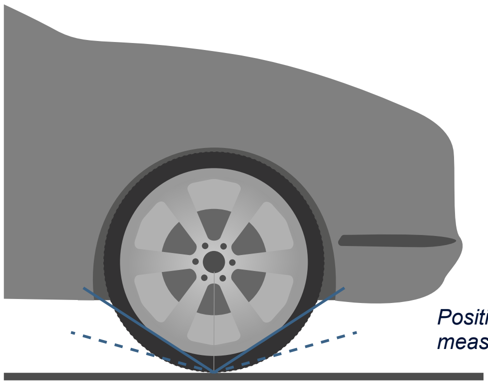
Microphones are used to record required airborne sound signals. Microphone stands, magnets or screw connections are suitable for fastening the microphones. In order to avoid structure-borne noise-induced crosstalk, it is not recommended to attach the microphones directly to the source or test object. If this cannot be avoided, decoupling elements such as foams must be used.



Mikrofonbestigung mit Entkopplung

Positioning of the microphone

In order to determine the sound pressure in the near field of the source, the microphones are to be positioned at a distance of about 10–15 cm from the surface of the source. Concerning measurements at flow openings (e.g., intake, and exhaust tailpipe), the microphone must not be positioned directly in the air flow. In practice, alignment at a 45° angle to the opening has proven effective. When it comes to the recording of tire noise at the inlet and outlet of the tire contact patch, the microphones are to be positioned centrally, as close as possible to the contact boundary but at least approximately 10 cm away from it.



Positioning of microphones for measuring tire noise

Microphone diameter

The most commonly used microphones in TPA are sound pressure microphones with omni-directional characteristics. The diameter of the microphones used is usually ¼ or ½ inch. ¼‘‘ microphones are capable of recording signals with a good signal-to-noise ratio. ½‘‘ microphones are used if a higher signal-to-noise ratio is required for subsequent evaluations. However, these microphones are not capable of recording as high sound pressures as can ¼‘‘ microphones. As a consequence, the selection of the microphone depends on the task.

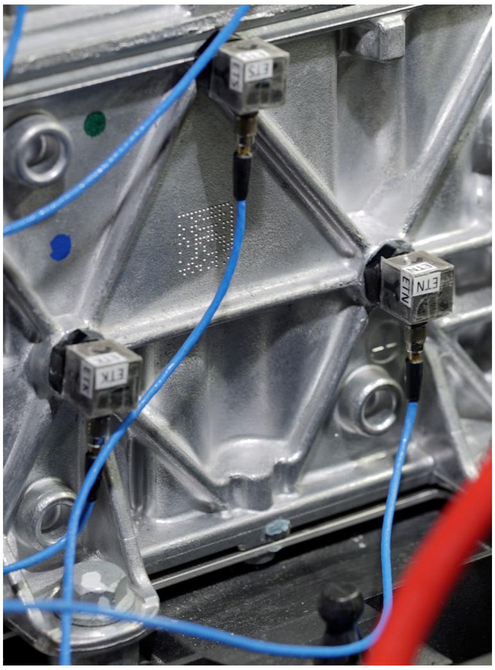
Accelerometers

IEPE (Integrated Electronics Piezo Electric)

Structure-borne sound signals are often recorded with accelerometers. In most cases, piezoelectric accelerometers are used for this purpose. With piezoelectric accelerometers, an electric charge is generated by the acceleration of a mass coupled to a piezo element. Using IEPE technology (Integrated Electronics Piezo Electric) reduces electrical interference susceptibility, so high signal quality can be achieved even with long cables to the sensor.

Charge sensors

Depending on the field of application, charge-capacitive sensors (charge sensors) are also used as an alternative. Charge sensors separate the role of the sensor from that of the signal amplifier. The advantage of these sensors is that the amplifiers can be configured in a more complex way. The disadvantage is, however, that long cables may be required to transport the sensor signal to the amplifier.



Accelerometers on a test structure

Mounting

Accelerometers can be attached in various ways, e.g., with magnets, wax, adhesive, or screw connections. The choice of coupling directly affects the frequency range that can be measured with the sensor. For a durable, temperature-resistant connection in TPA measurements, the accelerometers are usually glued to the measurement object. When attaching the sensors, it must be ensured that they are electrically decoupled from the measurement object. In order not to damage the glued sensors after the measurement, they need to be rotated for removal. All sensors that are suitable for adhesive mounting have a hexagonal base plate so that an open-end wrench can be used to detach them if necessary.

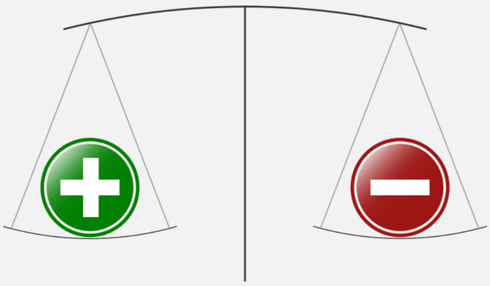
2. Determining structure-borne sound transfer functions

Impact hammer and shaker

In most cases, the static structure-borne sound transfer functions are determined using an impact hammer or shaker. When using an impact hammer, force pulses are applied into the structure via hammer stroke in order to excite it over a broad band. An impact hammer has a force sensor that measures the force applied during the stroke. Shakers usually consist of a vibration source and a force sensor to record the applied force. For excitation, the shaker system is fed with an excitation signal. Both types of excitation feature specific advantages and disadvantages:

Advantages of the impact hammer (compared to the shaker)

- Quickly ready for use, less time required, lower costs
- No transverse forces
- Easier excitation of high frequencies



Disadvantages of the impact hammer (compared to the shaker)

- Signal-to-noise ratio is usually lower
- Higher susceptibility to noise, especially during decay of the structure after pulse excitation
- Higher risk for nonlinear behavior of the structure (e.g., due to deformation)

Advantages of the shaker (compared to the impact hammer)

- High signal-to-noise ratio due to continuous excitation over a longer period of time
- Individual excitation signal with selectable frequency range
- Measurement of strongly attenuated systems is supported

Disadvantages of the shaker (compared to the impact hammer)

- Higher effort is required for installation / preparation
- Higher costs

Measuring transfer functions using an impact hammer

Measuring with an impact hammer

The range of forces that can be applied to a structure depends on the specific structure at the point of impact and the strength of force application. The following applies: The shorter the impulse applied, the wider the frequency spectrum of the force.

Using window functions

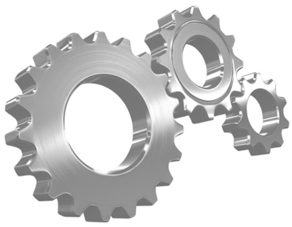
In order to avoid nonlinearities, force application should be as small as possible. If this makes the signal-to-noise ratio too small, force application needs to be increased or a more sensitive sensor must be used. If the signal of the force excitation is noisy, this will reduce the significance of the transfer function. The noise component can be minimized by using a window function that either allows the force pulse to pass or otherwise outputs the value 0. In order to reduce the leakage effect, the window function must decay to 0 at the end.

Spurious noise in the response signal

Even the system response to the force pulse, i.e., the acceleration signals, may be contaminated with noise. It is especially during the decay of the structure after impulse excitation that the superposition of the system response and noise make it difficult to distinguish the former. Spurious noise in the response signals often occurs when the force application point and the measurement point are far apart. Using suitable sensor technology and appropriate window functions will help to significantly reduce the noise component in the response signals. Typically, windows based on exponential functions are used.

Parameters for the measurement

Important parameters for the impact hammer measurement:



- **Trigger:** Triggering is usually done on the signal of the impact hammer. Test strokes can be used to predetermine the amount of force applied and to set the trigger level correctly. In most cases, the trigger direction is the rising slope of the force signal. To ensure that the beginning of the force impulse is not cut off, it is essential to use a pre-trigger (5-10% of the recording duration).
- **Recording duration** The recording duration is usually specified in 2^n samples (e.g., 2^{12} = 4096, 2^{13} = 8192, 2^{14} = 16384). The optimal recording duration depends on the measurement object. For this reason, it is advisable to start by recording a few untriggered test strokes and analyzing the decay times of the system responses. If the decay times are short, the recording duration may be chosen correspondingly short and vice versa. The longer the recording duration, the higher the frequency resolution of the resulting transfer functions.
- **Repetitions:** It is recommended to strike each measurement point with the impact hammer several times and to average the measurements. The usual number of strokes per measurement point is 5–6. Averaging reduces uncorrelated noise and provides statistical reliability to the results.
- **Level control:** Optimum level control of all channels improves the accuracy of the TPA results. The measuring range must be selected as small as possible (→ high signal-to-noise ratio) and as large as necessary (→ no overload).

Improving coherence

A meaningful transfer function can only be determined if sufficient energy was applied by the impact hammer and the measurement shows a high coherence between excitation and system response in the relevant frequency domain. The following measures help to reduce dips in coherence:

- Adjustment of the window functions for the excitation and the response signal
- Harder hammer tip (if coherence at high frequencies is noisy and the force signal is masked by noise)
- Positioning of the stroke during repetitions (i.e., strike as exactly as possible in the same position during repetitions)

If there are only isolated dips in coherence in the force spectrum, they are usually caused by anti-resonances of the structure.

Differences of the hammer tips

If the force spectrum shows no excitation in the relevant frequency range, this may possibly be changed by selecting a different hammer tip. The following applies:

- Rubber tip for low frequencies
- Plastic tip for medium frequencies
- Steel tip for high frequencies

Double stroke

If the force spectrum is not sufficiently constant in the relevant frequency domain, it may be assumed that more than one impulse was recorded per analysis block. If this is the case, the measurement needs to be repeated.

Spectrum with high frequencies

As a rule, the force spectrum is meant to fall off at high frequencies. If this is not the case, the system was probably excited with excessive high frequencies, which may result in nonlinearities. However, the force spectrum should not fall off too much, as otherwise the noise floor will mask the force signal.

Measuring transfer functions using a shaker

Correct use of a shaker

There are also some points to consider when measuring transfer functions with shaker excitation. For example:

- The coupling of the shaker to the structure must not affect its dynamic behavior. The test structure must be able to move freely despite the shaker.
- The application of force by means of the shaker is only to be done in the desired direction. To avoid transverse forces, a stinger is used to transmit the force from the shaker to the structure, for example.

Coupling of a shaker with stinger

If a large shaker system is not suitable to be used due to lack of space or with very lightweight structures, the Qlws Lightweight Shaker from Qsources can be used to determine the transfer functions.

Qlws Lightweight Shaker from Qsources

Signals for shaker excitation

For excitation, the shaker system is fed with an excitation signal. The following signals are suitable for determining the transfer function using a shaker:

- Transient or random signals with continuous spectra, such as pure random noise or burst random noise (continuous noise that is only active for a certain period of time within the measurement block)
- Periodic signals with discrete spectra, such as pseudo random noise, periodic chirp (sine with variable frequency over time) or stepped sine (discrete excitation at single frequencies)

Using window functions

Depending on the signal type, the recorded time signal of the shaker must be windowed in order to improve the signal quality.

Transfer function matrix

Position of the force application

As described above, defined forces are applied into the structure using an impact hammer or shaker to determine the structure-borne sound transfer functions. The position of this force application is supposed to be as close as possible to the actual position of the force application in the operating case. The better the points match, the more accurately the force can be described during operation.

Overdetermined matrices

For the matrix inversion method, a matrix with good matrix conditioning is crucial. In order for the matrix conditioning to be optimized, it can be overdetermined and/or regularized. Overdetermination requires accelerations to be determined at more response positions than are needed to describe the system. A common guideline is to have twice as many response than excitation points.

3. Performing operational measurements

Operational measurements with an active source

Operational measurements are performed using an active source (e.g., on a test site or test bench). All airborne and structure-borne sound channels are recorded synchronously. This allows the phase relationship between the different paths to be determined and taken into account. In addition, other measured quantities, such as speed, torque, and CAN, can be recorded.

Dynamometer of HEAD acoustics GmbH

Selection of the operating conditions

When performing the TPA in the time domain, there is no restriction to stationary operating conditions. The source is to be operated in any critical operating condition and the resulting sound pressures and accelerations are to be recorded. Critical operating conditions are usually those in which disturbing noise occurs.

4. Possible sources of error

Naming of the recordings

The amount of data that must be measured, analyzed and organized during TPA is very large. In order not to make any mistakes during evaluation, it must be ensured that the individual measurements can be reliably distinguished and assigned to the correct measurement points. The TPA Project in ArtemiS SUITE assists users with this task.

Systematic errors

Systematic errors in TPA may be caused by the following:

- In practice, for example on real vehicles, accelerometers cannot be placed exactly as theoretically assumed due to a lack of space.
- Due to cramped spatial conditions, certain measurement points cannot be reached correctly with either an impact hammer or a shaker. In such cases, force application does not take place exactly in the x, y or z direction. Consequently, the resulting transfer functions are subject to errors and falsify the results to a not inconsiderable extent. As a result, the forces occurring in real operation cannot be modeled with sufficient accuracy.
- Dependencies on changing operating conditions (e.g., change of temperature during operation) that cannot be sufficiently taken into account during modeling cause deviations.
- Another common source of error is that accelerations during operation on the side of the receiver structure are usually not only caused by the actual source under investigation. In a vehicle, for example, accelerations on the body side are not caused by the engine alone, but also by the rolling of the tires. If these accelerations are causally attributed to the source, deviations will occur in the modeling of the overall noise and the noise components.

Engineering Services of HEAD acoustics

This application note can of course only list a selection of practical tips and possible sources of errors. Thus, it only provides a brief insight into the subject.
The Engineering Services of HEAD acoustics can provide you with more comprehensive support for your TPA projects. Contact our expert to benefit from our many years of experience and expertise: engineering@HEAD-acoustics.com

➞ *Proceed to the fifth application note on transfer path analysis with notes on model validation*