Improved method for determining the absorption coefficient of high reflective surfaces

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Summary

The requirements for the exterior noise test tracks defined in ISO 10844:2014 are tightened relative to ISO 10844:1994 version. This certainly holds for the acoustical absorption of the road surface. The mandatory test for the acoustic absorption is the spot method that applies a two microphone impedance tube. Straightforward application of this method causes complications since for each microphone position destructive interference will take place at certain frequencies. This introduces a significant error in the determination of the transfer function between the two positions and thus in the calculation of the absorption coefficient.

We developed a procedure where signals are measured continuously at three microphone positions. Between each of the three pairs of positions the coherence function is measured. Occurrence of destructive interference at one position will result in loss of coherence for each pair that shares that position. Then we select at each individual frequency that pair with the highest coherence, and use that for the calculation of the transfer function, leading to a much better estimate of the absorption coefficient. This has shown to be a major improvement that reduces errors over the total frequency range and allows the determination of absorption coefficients below 2%.

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1. Introduction

Exterior noise measurements on vehicles and tyres are performed on a standardized test surface. This surface is prescribed in ISO 10844: 2014 [1]. ISO 10844 prescribes demands for the asphalt mixture, the acoustical environment and for the surface itself. The surface is described in terms of evenness, surface texture and acoustical absorption. The requirements for the surface are more stringent than they were in the ISO 10844: 1994 [2]. This certainly holds for the acoustical absorption that may not exceed 8% in each third octave band between 315 and 1600 Hz while in ISO 10844:1994 the limit value was 10% and averaging over frequency ranges was allowed.

The mandatory method to measure the acoustical absorption is the spot method prescribed in ISO 13472- 02 [3]. It uses a standardized impedance tube with two microphones to determine the acoustical absorption. However, straight forward appliance of this method on reflecting surfaces will cause complications because for each microphone position destructive interference will take place between the incoming and reflected sound wave at specific frequencies. This introduces a significant error in the determination of the transfer function between the two microphone positions and thus in the absorption coefficient, that is calculated from the transfer function. This paper describes an improved method to determine the acoustical absorption of dense surfaces, based upon the current measurement method.

2. Acoustical absorption of dense surfaces

The acoustical absorption of dense surfaces is measured with a conventional two microphone impedance tube, as standardized in ASTME 1050-98 [4] and ISO 10534-2 [5]. The application for reflective surfaces and the fixture necessary for sealing the impedance tube are described in ISO 13472-2. Figure 1 shows a preview of the system, including the fixture to seal the impedance tube on the road surface. Adhesive clay is used between the fixture and the surface to assure there is no sound leakage.

Figure 1. Impedance tube with fixture to measure the acoustic absorption of dense surfaces in situ. Top and bottom microphone position are used in this example

2.1. Working principle

A sound source generates plane sound waves in the tube. The sound pressures are measured at three positions with two microphones at different positions from the sample under testing. The complex acoustic transfer function of the microphone signals is determined and used to calculate the normal-incidence reflection factor, and the normal-incidence absorption coefficient.

The sound is measured at three positions, position 1 to 3, with position 1 being closest to the surface under testing and position 3 being the most far away. The microphone pair 1 and 3 is used to determine the transfer function in the lower frequency range, microphone pair 1 and 2 is used to determine the absorption coefficient in the higher frequency range. In doing so minimize the error in the phase of the transfer function.
The operator has to switch one microphone from position 2 to position 3 during the measurement because only two microphones are used.

This method is known to yield reliable results for conventional absorptive materials, but when applied to dense surfaces, serious problems were encountered when trying to establish the very low absorption coefficients defined in ISO 10844.

2.2. Interference at a microphone position

It was observed that at certain frequencies destructive interference takes place between the incoming and reflective wave at the position of one of the measuring microphones. When this is the case it is almost impossible to determine the transfer function correctly resulting in an incorrect reflection factor. In almost all of the cases such error will result in an increase of the calculated absorption coefficient. In combination with the very low limit value, such error may lead to failure to meet the requirements and thus resulting in non-compliance of the test track.

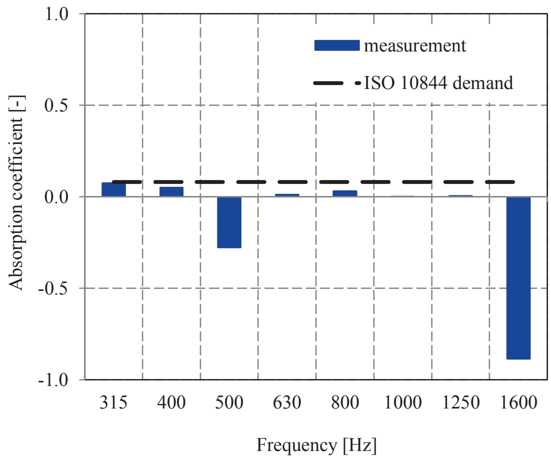

Figure 2. Absorption spectrum for a dense surface. Note that at certain frequencies the determination of the absorption coefficient is hampered by interference of the incoming and reflecting sound wave.

An example of this is given in figure 2 where the determination of the absorption coefficient is hampered in the 500 and 1600Hz third octave frequency band due to the interference taking place in front of one of the specific microphone positions, leading to impossible values for the absorption coefficient.

3. Three microphone method

We have improved the method by adding a third microphone to the system and measuring the signal simultaneously at all three positions. We can now calculate the transfer function between each pair of microphones.

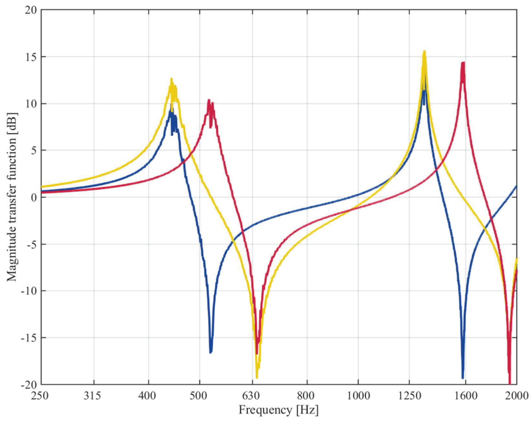

Figure 3. Transfer function for each two pair of microphones

An example of these transfer functions is given in figure 3. The graph shows that problems can be expected around 430, 520 and 640 Hz.

$$C_{xy}(f) = \frac{|P_{xy}(f)|^2}{P_{xx}(f)P_{yy(f)}} \tag{1}$$

where:

$P_{xy}(f)$ cross power spectral density
$P_{xx}(f)$ power spectral density of x
$Py_y(f)$ power spectral density of y

In addition to the transfer function we also calculate the coherence function for each pair of microphones is calculated with the formula below. The coherence functions of the three transfer functions, given in figure 3, are shown in figure 4.

Over the larger frequency range the coherence function is very close to 1. At certain frequencies, it can be noticed that two of the three coherence functions exhibit a significant drop to almost 0.1. This drop can be explained by destructive interference occurring at one microphone position. The drop is present in both transfer functions sharing that microphone position. However, the coherence for a third transfer function is still close to 1 and can be used to calculate the absorption coefficient. The method is thus based on monitoring the coherence and prevents using microphone pairs that show insufficient coherence value. There exists no free choice of microphone pairs. The phase sensitivity prescribes preferred pairs. Positions 1 and 3 for the lower frequency range and positions 2 and 3 for the upper frequency range. Only when the coherence function drops below a certain threshold value we switch to a pair of microphones with the highest value for the coherence function.

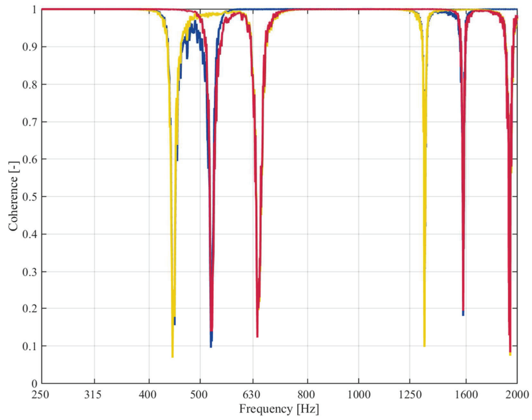

Figure 4. Coherence function for the transfer function of each pair of microphones

4. Comparison between two and three microphone method

Figure 5 makes a comparison between the two and three microphone method. It shows the absorption coefficient as a narrow band frequency. There is a clear peak in the absorption coefficient for the two microphone method around 460 Hz. In the three microphone method this peak disappears as we switch to the pair of microphones that is not influenced by this interference. This peak will

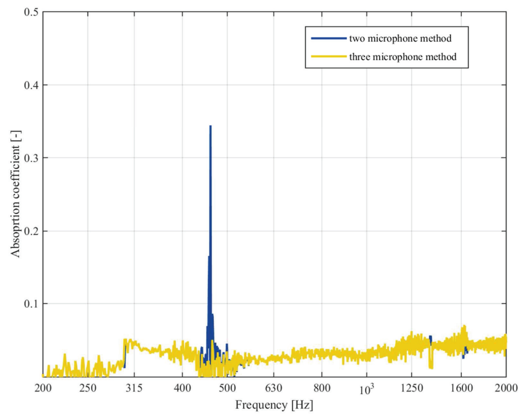

Figure 5. Absorption spectrum determined between the two micophone and three microphone method.

raise the value of the related third octave band with 0.02 to 0.03 which represents about 30% of the limit value in ISO 10844 of 0.08.

5. Addition benefits

Using the coherence function has additional benefits as it is an effective way to monitor the quality of the measurement. The operator can easily determine the influence of disturbing noise but also distortion of the input signal, such as caused by overloading the speaker. An example of the latter is shown in the figure below. Shown are the coherence functions for a measurement with the speaker in overload condition. The resulting absorption spectrum in third octave bands would most certainly be distorted due to this loss of coherence.

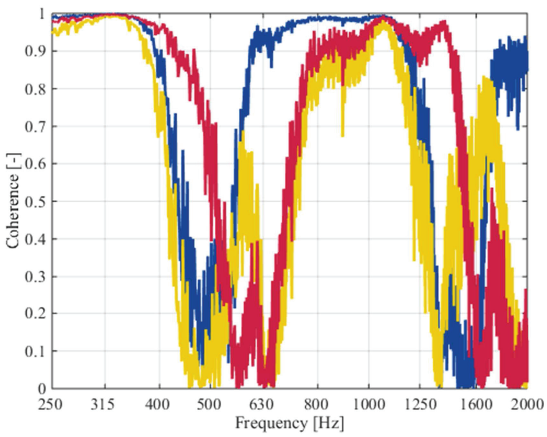

Figure 6. Coherence function for the transfer function of each pair of microphones in case of speaker overload

6. Conclusions

Straight forward application of the two microphone method on dense surfaces as defined in ISO10844 can result in destructive interference for a microphone position. This leads to an inaccurate determination of the absorption coefficient. The three microphone method presented here is designed to cancel out this limitation. A third microphone is applied to continuously record the sound at all three microphone positions and the coherence function is used to select the pair of microphones with the most accurate transfer function. This improves the accuracy of the measurement method significantly. In addition it enables monitoring the quality of the measurement in general and identifies problems with background noise and other disturbing factors. This leads in general to a much better estimate of the absorption coefficient.

Finally it was experienced that measurements can be performed much faster and with fewer errors since no shifting of microphones is required anymore and no errors in the interchanging are made.

References

[1] ISO 10844:2014, Acoustics – Specification of test tracks for measuring noise emitted by road vehicles and their tyres, 2014-05-12.

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[4] ASTM E 1050-98, Standard test method for impedance and absorption of acoustical materials using a tube, two microphones and a digital frequency analysis system.

[5] ISO 10534-2:1998, Acoustics – Determination of sound absorption coefficient and impedance in impedance tubes – Part 2: Transfer-function method.