Spatial variation of impedance and intensity measured close to a sample in the near field of a spherical sound source

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ABSTRACT

Apart from laboratory based techniques to measure the sound absorption properties of samples there are some *in situ* methods. But most of these methods are limited in frequency range, require large samples and/or are vulnerable to background noise or reflections.

With PU probes the sound pressure and particle velocity can directly be measured close to the material. A small *in situ* portable setup has been build that consists of a PU probe and a loudspeaker. The absorption coefficient is most often calculated using impedances models. In the past measurements have been done on relatively small samples (>0.1 m^2), in a broad frequency range (300-10000 Hz), under reverberant conditions (e.g. inside a car or concert hall), see [1-4]. Recently also models based on intensity have been investigated [5].

The small source-sample and probe-sample distance are the main reasons for the relatively small sample size requirement and the low influence to background noise and reflections. However due to the nearby source there are also interferences caused by the spherical wave front and near field effects. Both effects also depend on the angle of incidence. Although locally reacting material behavior is often assumed the absorption coefficient should actually be calculated by integrating measurements at all angles of incidence. Here the spatial effects of the impedance and intensity close to a sample surface are investigated. A sound source is positioned at 0.265 m from the material while the probe is moved in the horizontal direction across the surface.

INTRODUCTION

A small portable device is often used that combines a PU probe with a sound source which is similar to a true point source [2,4], see figure 1. Because a fixed configuration is used for the sample measurement and the calibration, positioning and orientation problems of the probe relative to the sound source are avoided.

Fig. 1. Portable PU in situ measurement setup

ABSORPTION MODELS

Nearly always impedance models are used to calculate the absorption coefficient from the measured pressure and velocity above a sample. Because of the nearby sound source corrections have to be made for the near field effects and the spherical wave front. The fairly uncomplicated mirror source model compensates for near field effects [1-4]. Also there are more elaborate models that compensate for both effects [1,6,7].

But these models assume that the sample consists of an infinitely thin material on a rigid impenetrable backplate, while in reality materials have a certain thickness. Sound waves partially reflect directly at the surface, but can also a certain amount penetrates the surface and travel through the material several times. This will cause standing waves inside the material which results in a big phase shift and deviations of the calculated absorption.

An alternative method to calculate the absorption is to measure the intensity instead of the impedance. The active intensity is calculated from the real part of pressure and velocity [8,9]. Integrating the intensity over a closed surface results in the radiated sound power in the far field. The absorption is then simply the ratio of the intensity I_1 measured above the sample and I_0 measured in the free field.

TEST DESCRIPTION

Measurements at all angles of incidence have to be integrated to calculate the absorption coefficient. Because substantial near field and interference effects can be expected the spatial distribution of the intensity and impedance across the surface is investigated.

A spherical sound source is positioned at a fixed position 0.265 cm above a large sample, while the probe is moved in the horizontal direction, see figure 2. The particle velocity normal to the surface is measured while the probe-surface distance was 5 mm. From distance $x = 0$ to $x = 0.56$ m measurements were done in 1 cm steps.

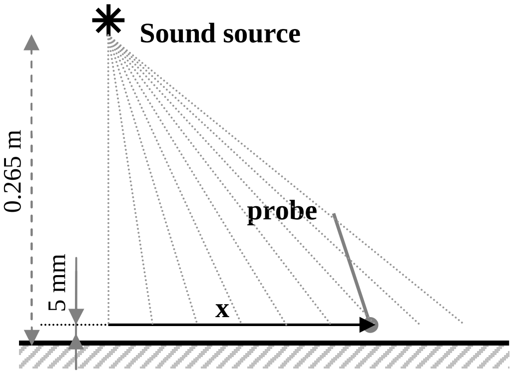

Fig. 2. The probe is moved in the x-direction in 1 cm steps across the surface

The next two chapters show the calculated intensity and impedance values at each position. The results are normalized to the measurement at position $x = 0$ and are compensated for the angle of incidence.

SPATIAL INTENSITY DISTRIBUTION

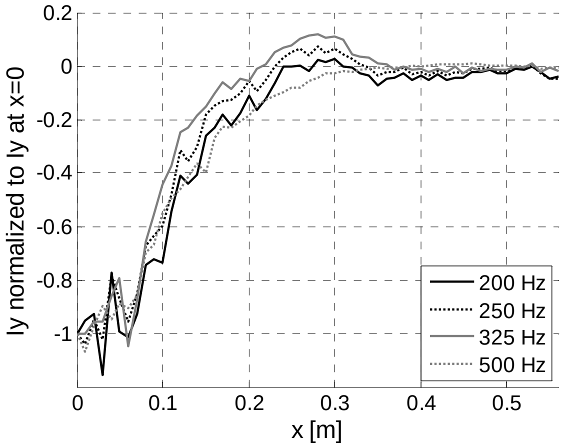

Fig. 3. Intensity along the x-axis at low frequencies

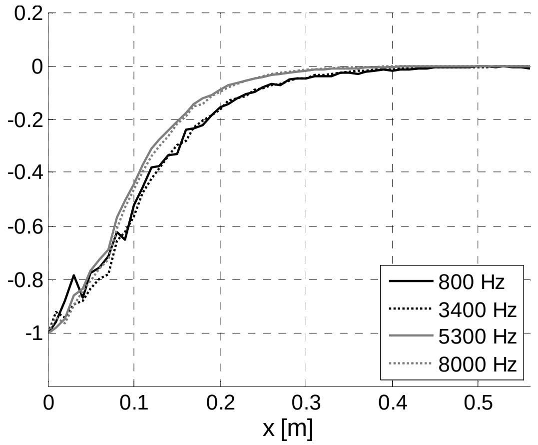

Fig. 4. Intensity along the x-axis at high frequencies

Figure 3 and 4 show the intensity distribution along the x-axis at several frequencies. The general trend is that the intensity is strongly negative at small values for *x* and is declining gradually.

An interesting observation is made at e.g. 250 and 325 Hz. Here the intensity is positive between $x = \sim 0.2\text{-}0.35$ m. This means the reflected intensity exceeds the ingoing intensity. A possible explanation for this behavior is the different angle of arrival of the reflected sound and the low absorption at those frequencies. I_1 will be lower than I_0 due to the slightly longer path length. However the normal components are measured instead. Effectively $I_0 * h/\sqrt{(h^2+x^2)}$ is measured. The angle of incidence of I_1 is smaller because the mirror source is positioned at $h+2d$ instead of h:

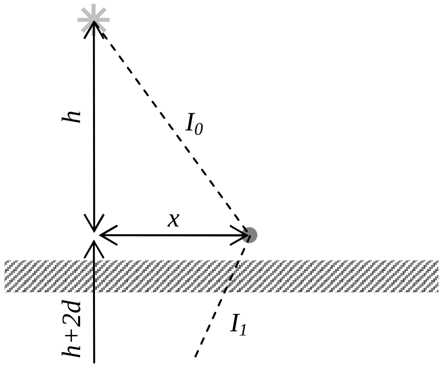

Fig. 4. Different angles of incidence for I_1 and I_0

SPATIAL IMPEDANCE DISTRIBUTION

Apart from some small deviations, the spatial intensity distribution is quite consistent throughout frequency. The next figures show the impedance distribution has a much bigger variation. Even thought the same measurement data is used, the impedance at 250 Hz seems to vary a lot at different positions. At high frequencies (> 800 Hz) strong interference effects are measured. As mentioned previously there are impedance models that attempt to compensate for the spherical wave front. But these models are not perfect, and as is also seen here the impedance can be strongly place dependent while positioning errors are easily made.

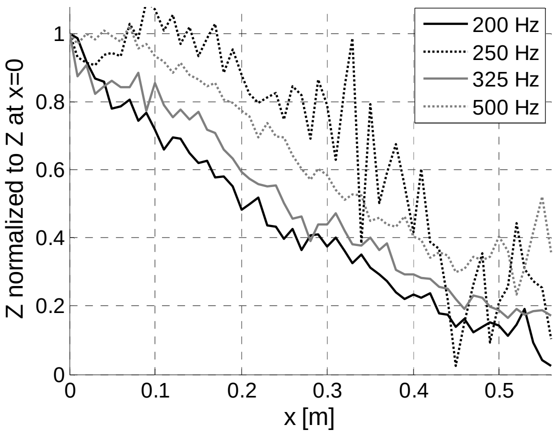

Fig. 5. Impedance distribution at low frequencies

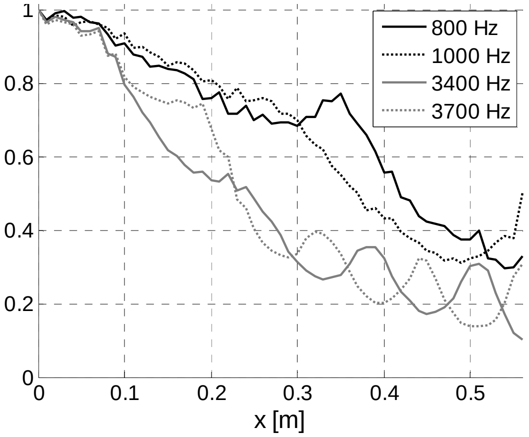

Fig. 6. Impedance distribution, middle frequencies

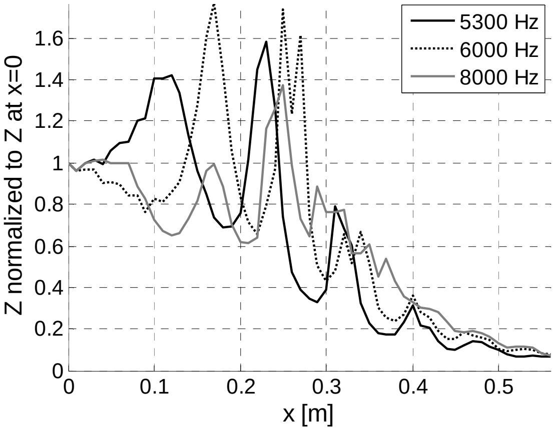

Fig. 7. Impedance distribution at high frequencies

CONCLUSION

A simple experiment has been performed to measure the spatial variation of the normal intensity and impedance across the surface of an acoustic absorbing sample. A sound source has been positioned above the surface while the probe is moved in the horizontal direction. The spatial variations of impedance are much higher than the intensity in the whole frequency range, especially above 800 Hz.

In order to measure the sound absorption coefficient integrated over all angles of incidence an intensity based approach might require less measurement positions than an impedance based model. Although there are complicated impedance models they are not perfect and susceptible to positioning errors. Methods to calculate the absorption based on intensity rather than the impedance are potentially more robust to measure oblique angles of incidence.

REFERENCES

[1] Measuring the free field acoustic impedance and absorption coefficient of sound absorbing materials with a combined particle velocity-pressure sensor, R. Lanoye, G. Vermeir, W. Lauriks, R. Kruse, V. Mellert, JASA p2826–2831, 2006

[2] In situ tubeless impedance measurements in a car interior, E. Tijs, E. Brandao, H-E de Bree, SIA Le Mans 2008

[3] In situ measurements of acoustic impedance for car applications: influence of forming effect, C. Sandier, C. Peteul, E. Guyader, J-L Guyader, Internoise 2006

[4] Large scale in situ acoustic absorption measurements in a theatre, E. Tijs, H-E de Bree, E. Brandao, DAGA 2009

[5] A Handheld Intensity Device for Measuring Absorption Properties in situ, E. Tijs, E. Druyvesteyn, H-E de Bree, Forum Acusticum, 2011

[6] Análise teorica e experimental al do processo de medição in situ da impedância acústica, E. Brandão, Final thesis, 2011

[7] An Iterative Method for Determining the Surface Impedance of Acoustic Materials In Situ, J. Alvarez, F. Jacobsen, Internoise, 2008

[8] A new sound intensity probe; comparison to the Bruel & Kjaer p-p probe, W. Druyvesteyn, H-E de Bree, J. audio Eng. Soc., Vol. 48, 2000

[9] A note on the calibration of pressure velocity sound intensity probes, F. Jacobsen, V. Jaud, JASA, 2006