

# Comparison of standing wave ratio method and transfer function method for measuring sound absorbing properties of 3d-printed samples

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## Introduction

Measurements in the impedance tube are very useful as they enable the measurement of sound absorption for normal incidence sound, under controlled conditions. Due to the small size of the samples (a few centimetres in diameter), they are frequently used in the development of new materials. Alternative solutions usually demand the construction of large samples, which is more difficult and expensive. Moreover, the impedance tube method can be carried out with relatively simple equipment in a normal room and does not need specialised test chambers [1]. A lot has been written about the accuracy of the measurement method, the effect of the mounting condition, etc. [2-4] However, a majority of these studies are concerned with open porous and homogenous materials.

This paper examines two 3d-printed samples with non-homogenous and anisotropic geometry by measuring them with two different methods in the impedance tube: the standing wave ratio method and the transfer function method. The tested samples contain open tube structures and are produced with Selective Laser Sintering from polyamide (PA12). Each sample (10cm in diameter) is measured in the impedance tube, following the approach of each technique. In the first case the measurements are taken at 1/3<sup>rd</sup> octave band centre frequencies and in the second from 50 to 1600Hz with a 2Hz interval. The measured results are juxtaposed to each other and to calculations based on acoustic theory. Besides indicating which method is more suitable for the specific type of non-porous absorbers, the advantages and disadvantages of each technique are discussed.

## Standing wave ratio and transfer function method

A loudspeaker is generating planar waves within the impedance tube. The resulting standing wave relies on the acoustic properties of the inserted sample. By measuring it, the normal incidence absorption coefficient can be calculated. This is such a common technique in acoustics that it is described also by international standards[1, 5, 6], as follows:

In the case of the standing wave ratio method, a movable microphone is used to define the ratio of the maximum and minimum pressure. From this ratio derives the reflection coefficient and from there it is possible to get the impedance and absorption coefficient.

The standing wave ratio method is very reliable and does not need microphone calibration. However, it only measures one frequency at a time and therefore the procedure becomes rather slow. It is a labour-intensive method and needs a lot of time to measure a large number of frequencies; as a result typically only 1/3<sup>rd</sup> octave band centre frequencies are measured.

In the case of the transfer function method, the sound source is emitting a broadband stationary noise signal. The transfer function, which is defined as the ratio of pressures, between two microphone positions is measured in the tube. This leads to the reflection coefficient of the sample for the same frequency band as the broadband signal. The impedance and absorption coefficient can be derived as well.

The second approach is accurate, reliable and obtains the absorption coefficient and impedance of the surface for a large range of frequencies (within limits) considerably fast.

## Methodology

This paper reports the results for two 3d-printed samples, which contain interference absorbers, tested with the method of the standing wave ratio and of the two microphone transfer function methods. The measurements of the acoustic absorption properties of each test sample were carried out in accordance with ISO 10534-1:1996 and ISO 10534-2:1998, correspondingly. The samples were measured 3-5 times, each with different mounting conditions, minimising the possibility of experimental error. For both methods, cylindrical samples with diameter of 100 mm were used. For the standing wave ratio method (B&K, type 4002) measurements were taken at the third-octave band centre frequencies: 100/ 125/ 160/ 200/ 250/ 315/ 400/ 630/ 800/ 1000/ 1250/ 1600 Hz. The transfer function method (B&K type 4206) acquires results from 50 to 1600Hz, which were measured with a resolution of 2Hz .

The samples are fabricated with Selective Laser Sintering (SLS) from polyamide (PA12) (fig.1). SLS is a powder-based additive manufacturing technique that works by

selectively scanning and sintering the surface of the raw-material with a laser [7]. SLS was chosen, among other AM techniques, because of its powder-based nature and its economical and fast features in production. The self-supporting capabilities of the technique allow the fabrication of highly complex internal air paths. Moreover, the post-processing only involves the removal of the unsintered powder using simple techniques such as using compressed air or brushes. Even though the sintered material presents some micro-porosity, it is not expected to perform as an open porous material.

The tested samples contain tubes with two open ends. Their resonant frequencies can be calculated based on [8]:

$$f = \frac{(2n-1) \cdot c}{2 \cdot (L_{tot} + \Delta L)}, \quad n = 1, 2, 3, \dots \quad [\text{Hz}] \quad (1)$$

As in Helmholtz resonators, the air mass co-vibrating at the pipe inlets leads, according to Fuchs [8], to an inlet correction to the length  $L$  dependent on the pipe radius  $r$ . In equation 1,  $\Delta L$  is calculated as  $0.8r$  (= the radius of the inlet).

The designs of the two samples can be shown in *Figures 2* and *3*. Sample GP.3.4 contains one air-path with a total length of 0.343 m and circular profile of 0.02m diameter. The first design frequency is 476Hz ( $n=1$ ). Sample GP.4.2 contains three air-paths with diverse lengths: 0.343m ( $L_1$ ), 0.515m ( $L_2$ ) and 0.686m ( $L_3$ ). All of them have a diameter of 0.015 m. The corresponding design frequencies for  $n=1$  are: 482, 325 and 245 Hz.



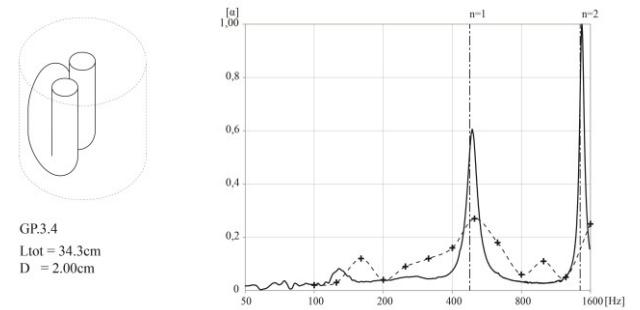
**Figure 1:** Samples GP.3.4 (right) and GP.4.2 (left) are tested in the impedance tube, using the transfer function method and the standing wave ratio method

## Results

*Figures 2* and *3* plot the measured normal sound incidence absorption coefficient ( $\alpha$ ) as a function of frequency (dashed and solid curves) together with calculated data (vertical lines). The results show that within certain narrow frequency bands high absorption peaks are found; the corresponding  $\alpha$  values are measured from 0.47 to 1 at peak frequencies between 288-1600Hz.

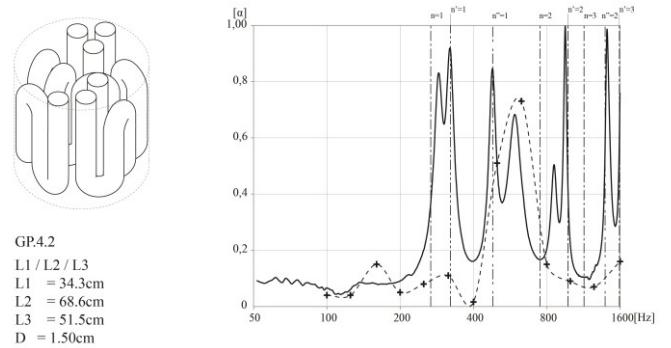
The measurements of sample GP.3.4 are in satisfying agreement with regard to the theoretical peak frequencies and show only small deviations from these calculated peaks. As shown in table 1, in the case of the transfer function method, the measured peaks deviate maximum 3% from

calculations; as in the case of the standing wave ratio the percentage deviation is 5-12%. However, the  $\alpha$  values are significantly higher in the case of the transfer matrix method, when compared to the standing wave ratio. This is likely due to the fact that the measurements with the standing wave ratio method are taken only at the third-octave band centre frequencies. Hence, the maximum peaks might not have been detected since they locate between the measured frequencies. It is notable that the dashed curve represents the interpolation of the  $\alpha$  values between the measured frequencies, while the crosses show the measured values.



**Figure 2:** measured results for sample GP.3.4. in the impedance tube, using the standing wave ratio (- + - + -) and the transfer matrix method (solid line)

Larger differentiations are observed in the measurements of sample GP.4.2 (fig. 3). The transfer function method detects 8 peak frequencies that are in satisfying agreement with theory. The deviation percentage is 0-30% (see table 1). It is notable that the highest percentile deviation corresponds to the longest air-path ( $L=0.686m$ ). This fact might indicate that the specific air-path might still contain un-sintered powder, which is affecting the results, or that there is an interference with neighbouring channels. Further investigation needs to be conducted to clarify the reason. The standing wave ratio method identifies only two major peaks at 500 and 630Hz. This might relate to the fact that the examined samples are performing sharp and narrow peaks and the measurements are taken only at the third-octave band centre frequencies. As a result, certain peaks are not detected since they locate between the measured frequencies. For this reason, it would be recommended to take measurements at smaller intervals, especially around the expected peak frequencies.



**Figure 3:** measured results for sample GP.4.2. in the impedance tube, using the standing wave ratio (- + - + -) and the transfer matrix method (solid line)

**Table 1:** calculated and measured peak frequencies and corresponding percentage deviations

L [m]	n	Calcu- lated Peak F [Hz]	Meas. Peaks - Transfer matrix	Percentage deviation [%]	Meas. Peak - standing wave ratio	Percentage deviation [%]
3.4	0,343	1	476	490	3	500
	0,343	2	1429	1478	3	1600
4.2	0,343	1	482	480	0	500
	0,343	2	1446	1416	2	-
0,515	1	325	322	1	-	-
	2	975	956	2	-	-
0,515	3	1625	1600	2	1600	2
	0,686	1	245	288	17	-
0,686	2	736	586	20	630	14
	0,686	3	1227	862	30	-

## Discussion

This paper examined two 3d-printed samples with two different measuring methods in the impedance tube: the standing wave ratio and the transfer matrix method. The examined sound absorbers are non-homogenous and anisotropic and perform sharp and narrow peaks.

Even though the standing wave method is reliable, it measures only one frequency at a time. In this experiment, measurements were taken at the third-octave band centre frequencies. This frequency set should normally give a sufficient impression for porous absorbers, which are expected to plot a more or less continuous curve as the absorption spectrum. However, for the examined samples, sound absorption depends on resonances. In this case, peak frequencies and the corresponding  $\alpha$ -values might not be detected and give wrong impression on the performance of the sample. For this reason, it would be recommended to take measurements at smaller intervals, especially around the expected peak frequencies.

The primary advantage of using the transfer matrix method is that it obtains the absorption coefficient for a large range of frequencies (within limits) with only a couple of quick measurements. It seems that in the case of resonant absorbers, which usually perform sharp and narrow peaks, it is more beneficial to take measurements with the transfer function method. However the standing wave ratio is a robust method and is a useful second check on results but requires much time in order to have high resolution results.

## Acknowledgements

The project is supported by Technology Foundation STW. More partners are involved: Materialise, Peutz, Merford and ARUP. Special thanks to Evert de Ruiter, Diemer de Vries and Lau Nijs.

## Literature

- [1] T.J. Cox, P. D'Antonio (2009), *Acoustic Absorbers and Diffusers: Theory, Design and Application*. Taylor and Francis, Abingdon.
- [2] K. V. Horoshenkov et al., “*Reproducibility experiments on measuring acoustical properties of rigid-frame porous media (round-robin tests)*”, *J. Acoust. Soc. Am.*, 122(1), 345–53 (2007).
- [3] A. Cummings, “*Impedance tube measurements on porous media: The effects of air-gaps around the sample*”, *Journal of Sound and Vibration*, 151 (1), 63–75 (1991)
- [4] N. Kino, T. Ueno, “*Investigation of sample size effects in impedance tube measurements*”, *Applied Acoustics*, 68, (11–12), 1485-1493, (2007)
- [5] Acoustics -- Determination of sound absorption coefficient and impedance in impedance tubes -- Part 1: Method using standing wave ratio, ISO 10534-1:1996
- [6] Acoustics -- Determination of sound absorption coefficient and impedance in impedance tubes -- Part 2: Transfer-function method, ISO 10534-2:1998
- [7] I. Gibson, D. Rosen, B. Stucker (2015), *Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing*, Springer
- [8] Fuchs, V.F. (2013), *Applied Acoustics: Concepts, Absorbers, and Silencers for Acoustical Comfort and Noise Control*, Springer, Berlin