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Helmholz-based absorbers for low frequencies and large spaces

Anders Homb
NTNU, Department of Civil and Environmental Engineering, 7491 Trondheim, Norway, anders.homb@ntnu.no
SINTEF Community, 7465 Trondheim, Norway, anders.homb@sintef.no

Requirements concerning universal design imply that acoustic demands must be fulfilled in a number of new building categories and user areas compared to previously. The sound classification standard NS 8175 provides normative requirements for reverberation time and sound absorption, which proves difficulty to satisfy at lower frequencies. To meet this challenge, a well-known method is to use resonant absorbers that might be tuned to more narrow frequency bands. Numerous designs have proven that well designed Helmholz resonators are very efficient in terms of adding damping to resonant modes, but in this paper the focus is on shortening the reverberation time. The aim of the work is to develop solutions relevant for large spaces, and absorbing properties in the frequency range between 100 and 300 Hz. Development of Helmholz-type of absorbers is based on existing literature as well as calculations using the WinFlag software. One prototype of absorber without porous layer in the cavity was constructed. In such solutions, a resistive layer play an important role to broaden the frequency response, involving measurements of the flow resistance. Another resonator including mineral wool in the cavity was developed for installing in an existing room for improving the reverberation time at lower frequencies. Finally, a comparison between calculation and measurement results will be given.

1 Introduction

Acoustic environment of large or medium size rooms tends to be unsatisfactory and often outside public requirement. This has a negative effect on the equivalent sound pressure level and certainly a negative effect on the speech recognition and speech transmission. Larger rooms may be divided into different categories depending on the planned activity in the room. In table 1, examples of such rooms are given. The table includes the Norwegian requirement from NS 8175 [1] regarding reverberation time (RT) and a comment on speech transmission index (STI). Rooms especially dedicated for presentation and education are kept outside of this presentation.

Table 1. Building category and reverberation time requirements

Category	Maximum RT (sec) *	STI recommendations
Gymnasium	0,2 x room height	> 0,6
Open plan offices	0,2 x room height	< 0,4
Restaurants, cafeteria, reseptions etc.	0,2 x room height	Individual evaluation

* From NS 8175 [1]

For all examples, the RT requirement depends on the room height. The standard accepts an increased RT at 125 Hz and the public requirement start at 250 Hz for gymnasia. But we recommend approximately the same RT in the whole frequency range including 125 Hz for gymnasia, see also [2]. The argument for this is raised speech level from male persons at lower frequencies and drum sound from sport activities. Measurements from gymnasia, restaurants and open plan offices often show reverberation time far above requirement level, especially at lower frequencies. This is often the case even when the room have been planned by an acoustical engineer. To get a more or frequency independent reverberation time, this challenge needs to be solved by membrane or Helmholz type of absorbers.

From manufacturers of sound absorbing solutions, documentation is fully available for numerous products based on porous absorber type and to a certain degree perforated or slatted panels for ceilings. But it is a huge lack of documentation on Norwegian products especially planned for low frequencies and robust wall mounting solutions. We therefore initiated a student work on this, aiming to present optimized Helmholz absorbers for this frequency range. The paper will present some preliminary work on this together with some experiences on measured and calculated properties from field and laboratory objects.

2 Calculation principles

Resonant type of sound absorbers like Helmholz type have been used for many years and in many different applications because they can provide high absorption at low frequencies. The usual construction is a porous absorber or porous lining between the hard wall backing and the perforated or slatted panel. The principal mass of the resonator is the air in the holes or slits in the panel as the panel itself is normally very stiff. The stiffness is provided by the air volume and the resistance of the resonator are provided by viscous effects of the porous liner or porous absorber.

Several research studies have been carried out for several decades on this topic and manufacturers have adopted the theory for developing solutions for the market. Theory for prediction is available in a number of papers and textbooks. In this paper we will mention reference [3 to 8]. But as mentioned, such theory is to a low degree adopted by Norwegian manufactures of slatted panel systems.

In this paper, equations for calculating the absorption coefficient of Helmholz like absorbers will not be given. Theoretical calculations may be based on analytic equations, see for instance [9], transfer matrix method or FEM models. In this paper calculations have been based on the transfer matrix method implemented in the NorFlag software [10]. For simplified calculations of the resonance frequency of maximum absorption, the following analytic equations from [11] may be used.

$$f_0 = \frac{c_0}{2 \cdot \pi} \sqrt{\frac{\varepsilon}{l \cdot (d + \Delta d)}}$$

$$\text{with } \varepsilon = \frac{S}{S_0} \quad \text{and} \quad \Delta d = -\frac{2 \cdot b}{\pi} \cdot ln\left[sin\left(\frac{\pi \cdot \varepsilon}{2}\right)\right]$$

ε= perforation, l= distance from hard wall/ceiling, d= panel thickness, Δd= correction term panel thickness, b=slot width

In the normal case the slatted panel could typically be an assemblage of parallel harp edged "beams" or separated ribs of rectangular cross section with a specified thickness and width. The distance between the ribs is characterized by the slot width, see figure 3 and [10]. The width of the beams goes into the parameter centre-to-center distance between ribs. The density of the material is also an input parameter for calculation of the equivalent mass impedance of the solution. To obtain a high absorption coefficient of a resonance absorber the panel must be combined with a porous layer, a porous facing or a combination placed close to the slit. This is to give the necessary resistance component to the system. Input numbers are necessary on the total airflow resistance (Pa s/m). Results from measurements of the airflow resistance of some relevant products will be given in chapter 3. According to theory, the model may give unreliable results for frequencies above the fundamental resonance frequency for wide slits combined with a very high percentage open area (estimated to above 30-40 %).

3 Helmholz absorber prototype

The motivation for developing a prototype absorber have several reasons. For application in gymnasia or other room categories, the percentage open (slit) area needs to be limited to give a robust surface structure. Secondly, a goal was to suggest a solution as simple as possible, for instance without thick layers of a porous absorber. Filling the air space with porous material reduces the lateral sound propagation in the air space making the absorber reasonably locally reacting. To obtain the same effect in the no-absorber case, rigid walls subdividing the air space should be investigated. The prototype absorber was therefore planned without a porous absorber in the cavity but use of a porous facing attached to the frontend plate. Drawings of the first prototype developed by Sæle [12] is given in figure 1 with some geometrical information in table 2. The back plate is actually not necessary but installed to ensure air tightness towards the subdividing elements and towards the laboratory floor.

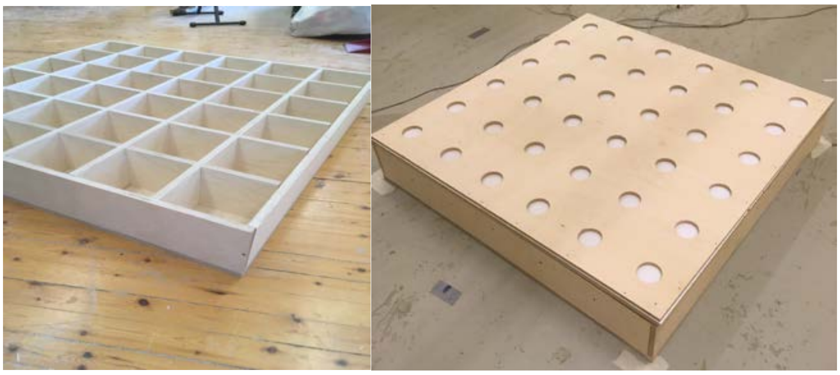

Figure 1. Picture of the prototype with and without the top plate, from [12]

Table 2. Prototype information

Perforation holes	Slit thickness, d (mm)	Average area per hole (mm^2)	Porous fabric type	Cavity depth (mm)
Ø 40 mm	30	30000	Venus A	Air, 150
Ø 65 mm	30	30000	Venus A	Air, 150

The overall task was to develop efficient absorbers "tuned" for the 125 and 250 Hz octave band. Preliminary calculations were carried out to determine geometrical numbers of the cavity and diameters of the holes. But in addition, reliable airflow resistance values were necessary for the predictions. It was measured in an instrument setup at NTNU according to method B in ISO 9053 [13]. In table 3, results from airflow resistance measurements are given. Standard deviation from the measurements has not been calculated, but the spreading among the selected layers have been within ± 4 %.

Table 3. Results from airflow resistance measurements of different materials, from [12].

Sample material	Numbers of layers	Airflow resistance, single layer (Pa s/m)
Woven glass fiber, Glava white 126 g/m^2	7	229
Woven glass fiber, Glava black 126 g/m^2	7	310
Glass fibre sacking, Glava Venus A 180 g/m^2	10	108

Based on input data from table 2 and table 3, calculation of the absorption coefficient has been carried out in NorFlag software [10] with the option of diffuse incidence. Results from these calculations are given in figure 2.

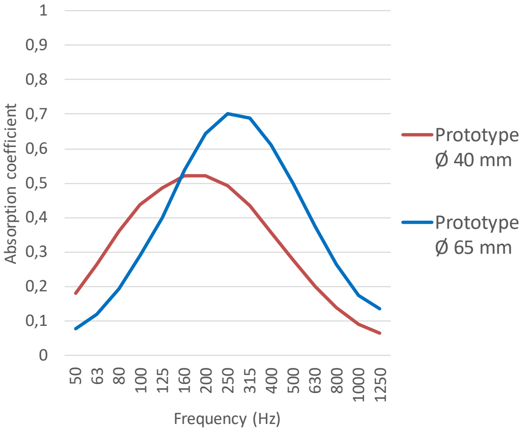

Figure 2. Calculated absorption coefficients for prototype, hole diameter 40 mm and 65 mm

Results from the Ø 40 mm object show maximum absorption coefficient at 160 to 200 Hz, and approximately at 250 Hz for the Ø 65 object. The latter one according to the overall goal, but the first one a bit higher than the original target. Object with the biggest holes gives higher maximum absorption and at higher frequencies. The shape of the curves indicates also a relatively broadband absorption behavior. The task was also to measure these objects in the laboratory and determine the measured absorption coefficient. Unfortunately, some mistake was done and the porous facing was damaged in a number of holes. It was also expected that the test area of the box was too small for accurate absorption data and far below object size requirements in ISO 354 [14]. Reliable measurement data of the absorption coefficient of this prototype is therefore so far not available

4 Helmholz examples from a filed object

A measurement example from a "cafeteria" show the necessity of improving the acoustic condition in this room. Before treatment the surfaces was a glass wall, concrete floor with a parquet on top and other surfaces of 1 or 2 gypsum board layers. It was decided to optimize a slatted panel wall to decrease the reverberation time especially in the frequency range 100 to 250 Hz. Figure 3 show principal design geometry of such slatted panels. Solution chosen for this room was a combination of two slit widths and associated center distances. In an upgrade version a porous facing was attached behind the panel. In figure 3 and table 4 essential information regarding this solution is presented.

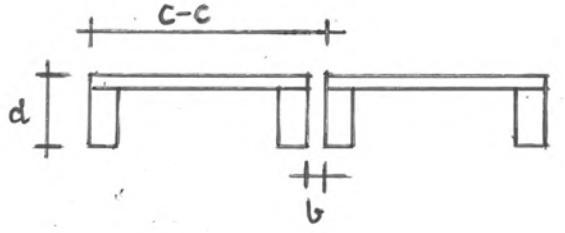

Figure 3. Design geometry for slatted panels

Table 4. Slatted panel information

Slatted panel	Slit thickness, d (mm)	Slit width, b (mm)	Center-distance slits (mm)	Porous fabric type	Porous backing (mm)
Section I	60	10	200	Woven glass fibre, white	Min.wool 150 mm
Section II	60	15	105	Woven glass fibre, white	Min.wool 150 mm

Measurements of the reverberation time have been carried out in several steps of the installation process towards an acceptable reverberation time in the room (people talking simultaneously) including installation of a sound absorbing ceiling. From the different measurements, it has been possible to determine relatively accurate, the equivalent absorption area before and after installation of the slatted panel wall. But the room (before treatment) fulfill of course not the requirements in ISO 354 regarding determination of absorption coefficient. But the results indicate the possibility of determining the properties from well controlled measurements in situ. Figure 4 show absorption coefficient numbers from predictions according to [10] and analysis of measurement results.

Calculation and measurements show the same, overall shape of the sound absorption coefficient. The results also show maximum sound absorption approximately at the same level, but the measurements show of course some deviating values in the frequency domain compared with the calculated curve. At medium and higher frequencies, the deviation is significant, but not surprising due to other absorbing elements in the room. This comparison show that it is possible to (a certain degree) verify calculations by accurate field measurements, at least when the equivalent sound absorption area is limited before the installation process.

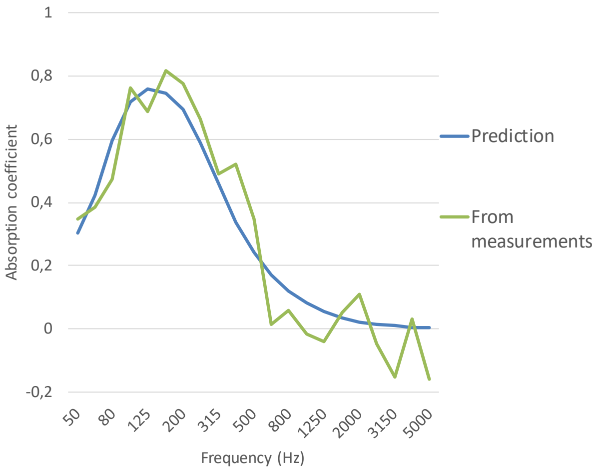

Figure 4. Absorption coefficient numbers from predictions and measurement analysis.

5 Helmholz examples from laboratory objects

A number of laboratory measurement results exists on slatted panel systems based on the Helmholz principle. Major part of data is probably ordered by manufacturers and not independent published. It is also difficult to get detailed information on involved products (airflow resistivity for instance) and absorption coefficient data is normally limited to octave band numbers. For this paper, the intention has been to look for some relevant measurement examples for comparison with calculations. Comparison of data and calculations in the following is based on examples from [15]. These measurement results from probably fulfil ISO 354 [14], but due to the age of this data we cannot verify this. Some generic solutions have been chosen for comparison with measurements. But still we had to estimate some material parameters concerning the porous layers. In table 5 essential information regarding example objects is presented. Figure 5 show comparison of measured and predicted results based on examples from [15].

Table 5. Example objects information

Slatted panel	Slit thickness, d (mm)	Slit width, b (mm)	Center-distance slits (mm)	Porous backing (mm)	Airflow resistivity	Porosity
N7	15	15	85	75 Rockwool	10	90
N8	14	20	165	75 Rockwool	10	90

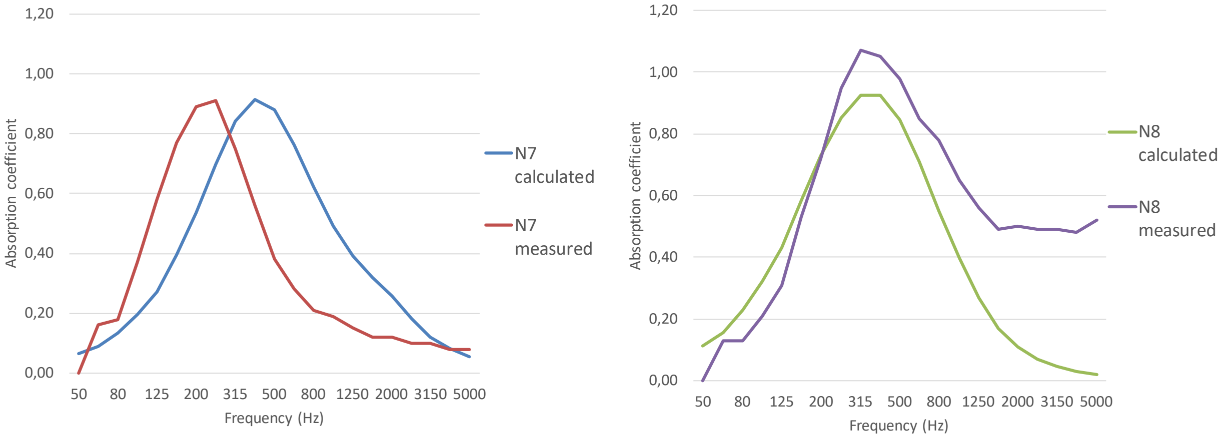

Figure 5: Comparison of measured and predicted sound absorption coefficients.

Comparison of calculation and measurements show the same, overall shape of the sound absorption coefficient at lower and medium frequencies. The results also show maximum sound absorption approximately at the same level, but the N7 example in figure 5 show a frequency shift of the maximum absorption coefficient. Other calculation results and comparisons also show calculated maximum absorption at a higher frequency than the measured one. Number of attempts have been made to modify the porosity and airflow resistivity but without significant changing the frequency of maximum absorption. These examples show that it is possible to achieve high correlation between measurements and calculations from NorFlag but deviating results may also be the case. In further work, we will try to examine the reason for the deviations and make a more comprehensive study between measurement results from laboratory and calculations.

6 Summary

The project started with the aim of developing a resonant absorber especially planned for low frequencies and robust wall mounting solutions. A student work was initiated, aiming to present optimized Helmholz absorbers for the low frequency range. One prototype of absorber with empty cavity was constructed but where a resistive layer play an important role to broaden the frequency response. Unfortunately, reliable measurement data is not available of this prototype, partly because of too small test area of the box. In the second section of this paper, field measurement results have been carried out to determine the sound absorption coefficient of a Helmholz absorber from measurements in situ. Acoustical improvements where highly needed in a "cafeteria" and an installation process was initiated. The reverberation time was measured before and after the acoustical treatments. Results show that it is possible to verify calculated absorption properties by measurements in situ, at least when the existing absorption area is limited. But on the other hand, a very high accuracy on the measurement result cannot be expect. In the last section of the paper comparisons was made between calculations and laboratory measurements of slatted panels. Comparison of calculation and measurements show the same, overall shape of the sound absorption coefficient at lower and medium frequencies, but for numbers of objects a frequency shift of the maximum sound absorption occur. In further work, we will try to examine the reason for the deviations and make a more comprehensive study on applied solutions based on slatted panel absorbers.

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