Study on the Effect of Back Cavity and Front Panel Materials on the Sound Absorption of Distributed Mode Absorbers

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Introduction

Sound absorbing materials integrated into architectural design elements are important in the field of room acoustics. Especially a suitable amount of reverberation time, depending on the purpose of the room, is essential in order to guarantee for instance speech intelligibility or a decent sound of rooms. Target reverberation times are therefore specified in DIN 18041 [1]. The Reverberation time can be attenuated by different types of sound absorbers, such as porous or resonant absorbers [2]. Where it is relatively straight forward to attenuate sound energy in the high frequency range by means of porous absorbers or Helmholtz absorbers in combination with porous material (see Fig. 1 red and yellow line), it can be very challenging to reduce sound energy at low frequencies. Due to long wavelengths, big structures would be required that are expensive and often cannot easily be included into interior design. To overcome this, resonance absorbers can be used that, however, are operating in a small frequency range only (Fig. 1 violet line). The absorption is to be expected around the occurring resonant frequencies of the vibrating membrane or plate [3], whereby resonant absorbers are often tuned to only one main resonance frequency.

In the current project the aim is to utilize several resonances (modes) of the membrane for absorption, in order to increase the effective frequency range and to design absorbers that can fill the gap between resonant and porous absorbers in the low-mid frequency range. Therefore, low-stiffness membranes are to be designed which incorporate resonances distributed over the requested frequency range of 50 Hz to 400 Hz (Figure 1 - black line). Due to the approach of distributing natural modes in the frequency range of interest by sophisticated membrane design, these absorbers are referred to as *Distributed Mode Absorbers (DMA)*. Next to a wider range of operation, these DMAs are supposed to be smaller and less expensive than conventional plate absorbers. Furthermore, one of the core ideas of this project is to integrate DMAs into furniture by using it for instance as front plates of cabinets or drawers.

To start with, prototypes with simple, low-stiffness membranes have been designed and built. Subsequently, the absorption coefficients of these prototypes have been measured, the results of which are being presented in the following. In the next sections at first a brief description of the used prototypes and the measurement procedure will be presented, followed by an analysis of the results. Finally, the results will be discussed and further steps in the project will be outlined.

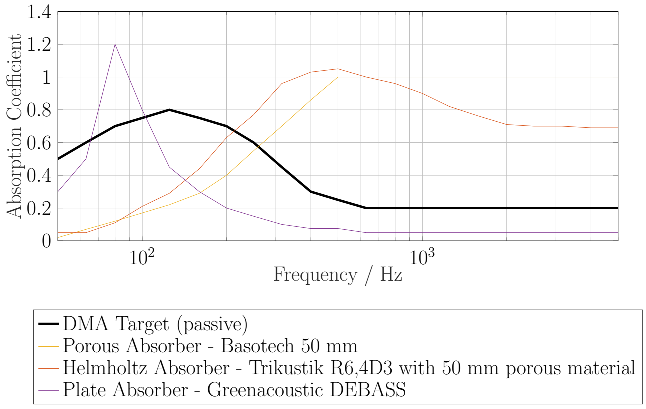

Figure 1: Comparison of different sound absorber types using examples available on the market; with porous absorbers (yellow), Helmholtz absorbers in combination with porous material (red) and plate absorbers (violet). Furthermore, a DMA target absorption curve is being displayed (black).

Universal Prototype

In order to predict the modal behavior of different configurations of DMAs, simulations were carried out beforehand (presented in [4]). By doing this, the dimensions of prototypes and possible membrane materials have been determined. With these simulations it was possible to predict the displacement behavior of the membranes and hence, it was possible to predict the frequencies at which absorption might occur. However, it was not yet possible to predict the absorption coefficients. For the purpose of measuring the absorption performance of different DMAs it was necessary to build actual prototypes. Since several configurations were to be measured, a design was chosen that allows for an easy exchange of front panels and back volumes.

The final DMA prototypes, with the outer membrane dimensions of 460 mm by 560 mm consist of a back volume with 5 rigid walls (19 mm MDF) and a flexible front membrane glued to an MDF frame (clamped bearing behavior). To easily exchange the membranes the frames are attached to the back volume using furniture connectors. Additionally, the size of the back volume was adjustable by optionally inserting a 39 mm thick wooden plate at one of three positions, yielding in back volumes of approximately 4.4 l, 13.2 l, 26.4 l, and 46.7 l. In the following these back volumes are referred to as BC020, BC060, BC120, and BC212, respectively, where the numbers are indicating the height of the back cavity in mm. Two different materials have been used as membranes. On the one hand, *High Pressure Laminate*

(HPL) was used in two different thicknesses of 1.3 mm and 3 mm, respectively. On the other hand, membranes were made from 2 mm *Plexiglas*. All prototypes have been manufactured by our project partners in *Hommel Manufaktur GmbH*. Given the four different back volumes and three membrane types, in total 12 different configurations could be applied.

Setup and Analysis

The absorption coefficients were measured according to ISO 354 [5] in the reverberant room of *TU Dresden* (see Figure 2). Absorption coefficients were calculated from reverberation times measured with and without samples. To reach the required sample area of 12 m^2, 48 DMAs were needed in each condition. Because of the high number of necessary DMAs it was decided to built the prototypes in the adjustable way mentioned above.

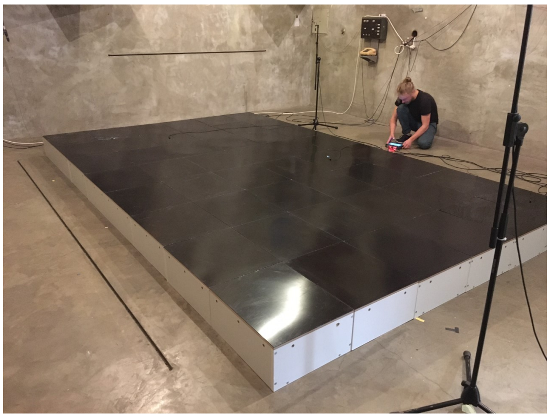

Figure 2: Measurement setup in reverberant room. 48 DMAs (here with Plexiglas membrane) sum up to a sample size of approximately 12 m^2.

In a first series DMAs with 2 mm Plexiglas and 1.3 mm HPL membranes have been measured. In a later series all configurations with HPL 3 mm membranes were assessed. The second series was necessary because of delays in delivery of the requested material, due to the current market situation.

Four microphones (*Microtech Gefell M-370*) were placed in the room. Together with three different loudspeaker positions, for each of the conditions a total of 12 source-microphone combinations were measured that have been averaged according to ISO 354. In the first series three identical 3D-printed dodecahedron loudspeakers were used [6], which were pre-installed in the reverberant room. However, some of the results seemed to be less accurate at very low frequencies (below 90 Hz), which was possibly evoked by the weak frequency response of these speakers in this frequency range. This is why in the second series *GENELEC 8250A* loudspeakers were used that exhibit a flat response down to approximately 50 Hz. In a previous work it was shown that the directivity of this kind of speakers does not remarkably affect the absorption coefficients measured in a reverberant room. In particular, at low frequencies below 100 Hz spherical radiation can be assumed also for this type of speakers [7].

Figure 3 displays the absorption coefficient for one DMA configuration (HPL 1.3 mm, BC120) measured with the two different loudspeaker types. It shows the absorption coefficients are very similar at frequencies above 90 Hz. However, below 90 Hz large deviations can be observed. Obviously, the absorption coefficient is systematically lower for measurements using the pre-installed speakers in this frequency range. Hence, a reliable evaluation of the results from the first series is only possible at frequencies above 90 Hz.

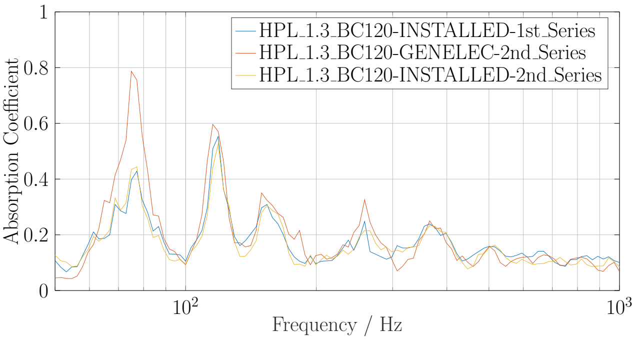

Figure 3: Comparison of the different speakers that have been used. The blue line represents the absorption coefficient of a DMA (1.3 mm HPL, BC120) from the first measurement series using the pre-installed dodecahedrons [6]. The yellow line represents the results for the same absorber type from the second series, using again the pre-installed speaker. It is included to show the reproducibility. The red line indicates the results of the measurements done with the GENELEC speaker in the second series. Obviously, using different speaker types results in deviations in the results below 90 Hz. This is caused by the frequency response of the 3D-printed speakers that do not radiate enough sound power at frequencies below 90 Hz.

According to ISO 354 reverberation times are calculated in third octave frequency bands. Since the DMAs are supposed to show sharp resonance peaks it was decided to display the results within this paper at an increased frequency resolution of 1/24 octave bands. Except of a changed filter bank the procedure to calculate the absorption coefficients was done according to ISO 354.

Results and Discussion

Evaluating the gained results reveal significant differences in the absorption coefficient curves among all the different DMA configurations. In the following, the results will be examined. At first, the influence of the membrane type is investigated. Afterwards the influence of different back volumes will be discussed.

Influence of the Membrane

In order to investigate the influence of different membrane materials on the absorption coefficients, Figure 4 shows the results of three different membrane types at a constant back cavity height of 60 mm (BC060). Obviously, the material has a big effect on the frequencies at which absorption occurs. This correlates with the assumption that absorption takes place only around resonances of the membranes, which are different for every material. However, also the highest peak values differ for different materials. Where membranes from 2 mm

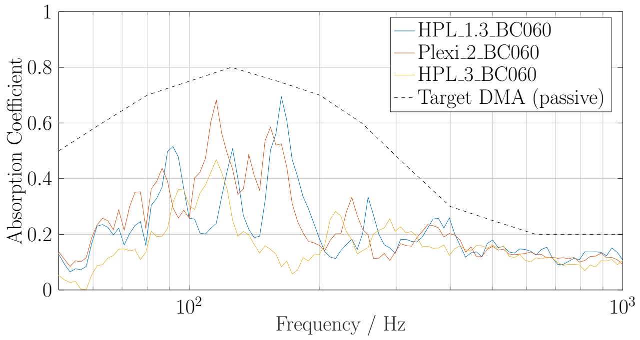

Figure 4: Absorption coefficients for DMAs with a **back cavity height of 60 mm** and different membrane materials. As a reference also the possible target curve of a passive DMA taken from Fig. 1 is plotted (black dashed line).

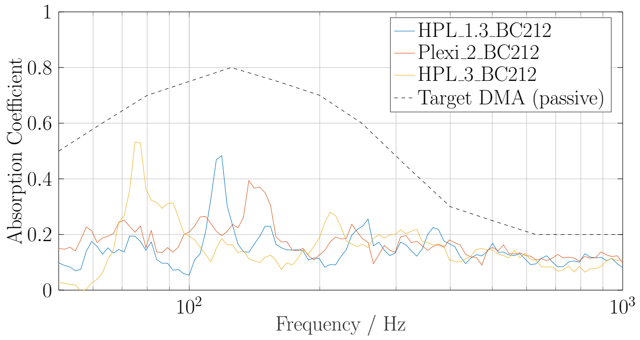

Figure 5: Absorption coefficients for DMAs with a **back cavity height of 212 mm** and different membrane materials. As a reference also the possible target curve of a passive DMA taken from Fig. 1 is plotted (black dashed line).

Plexiglas and 1.3 mm HPL reach quite similar maximum peaks, the maximum peak value for 3 mm HPL is more attenuated. This is caused by different material and structural parameters (e.g. HPL 3 mm inhabits a significantly higher bending stiffness). Next to higher peaks, it is also shown that for the first two materials there are more absorption peaks in the frequency of interest (50 Hz to 400 Hz). Again this is directly related to the modal behavior of the plates.

To act as a reference the possible target absorption coefficient curve from Figure 1 is depicted in Figure 4 as well. Apparently, the highest peaks of the absorption coefficients of the DMAs with 2 mm Plexiglas and 1.3 mm HPL membrane almost reach the target absorption values at certain frequencies. However, further membrane tuning is required to get even more modal peaks into the desired frequency range and to spread the peaks itself over frequency. The first requirement can be achieved by designing more sophisticated membranes with e. g. non-homogeneous thickness (steps or carvings). The latter one can be reached by adding damping layers to the membrane.

In general, the overall absorption of the single peaks should be increased as well. Therefore, it will be useful to insert porous material within the back cavity. For instance in [8] it is mentioned that this can add a value of 0.2 to 0.3 to the absorption coefficient.

Similar tendencies can be seen also for back cavity heights of 20 mm and 120 mm. Here again, HPL 1.3 mm and Plexiglas 2 mm membranes show more absorption peaks in the frequency range of interest compared to DMAs with 3 mm HPL membranes. Also the amplitudes of the highest peaks are in general higher for the previous two materials than the ones of HPL 3 mm. Only in the BC212 case the peak of HPL 3 mm exceeds the peaks of the other two DMAs (see Figure 5). Furthermore, in this condition for all materials only one main absorption peak can be observed. This seems to be due to systematic errors, as the first resonances shift to very low frequencies, less than 90 Hz. As pointed out before, the results of the first series (HPL 1.3 mm and Plexiglas 2 mm) are questionable at low frequencies. Hence the disappearance of peaks might be caused by the insufficient sound radiation of the speakers at these frequencies, rather than by an effect of the DMAs.

In summary, the highest absorption values could be achieved with a back cavity height of 60 mm. These results can be seen as a very good starting point given the very simple membrane design. Further membrane optimization, however, is required in the future steps.

Influence of the Back Volume

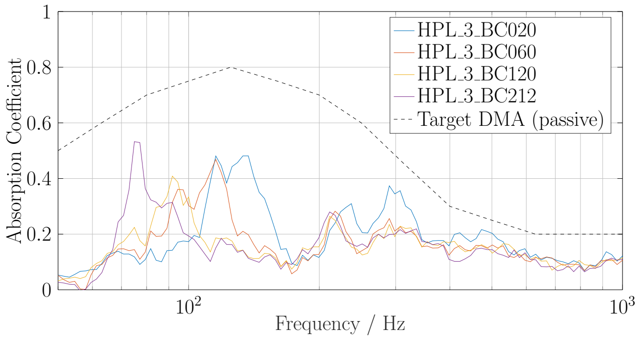

Figure 6: Absorption coefficients for DMAs with **3 mm HPL** membranes and different back volumes. As a reference also the possible target curve of a passive DMA taken from Fig. 1 is plotted (black dashed line).

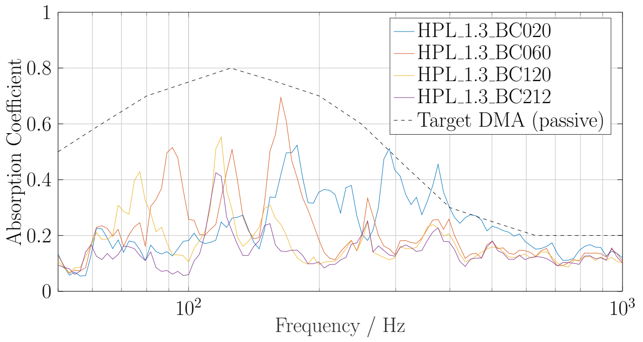

Figure 7: Absorption coefficients for DMAs with **1.3 mm HPL** membranes and different back volumes. As a reference also the possible target curve of a passive DMA taken from Fig. 1 is plotted (black dashed line).

Next to the influence of the membrane material, also the enclosed air volume behind the membrane affects the absorption coefficient of the DMAs. Figure 6 displays the

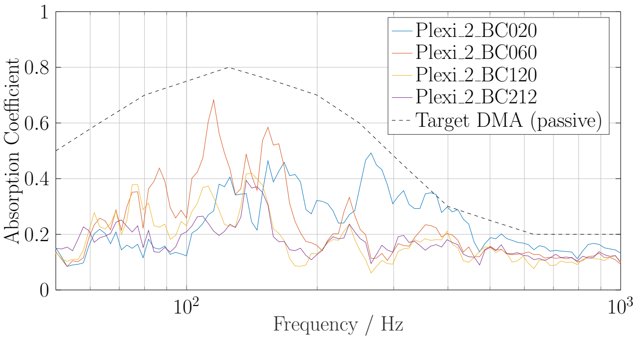

Figure 8: Absorption coefficients for DMAs with **2 mm Plexiglas** membranes and different back volumes. As a reference also the possible target curve of a passive DMA taken from Fig. 1 is plotted (black dashed line).

absorption coefficients of four different DMAs with 3 mm HPL membranes, each with a different back volume. The absorption coefficient curves exhibit one main absorption peak between 70 Hz and 140 Hz, depending on the back volume, and small peaks at around 200 Hz and 300 Hz. Whereas the peaks at higher frequencies are mostly independent of the back volume, the main peak is highly related to the back volume. This has been described before in [9]. As seen in Figure 6 the peaks shift up in frequency when the volume decreases. These results match with the simulated displacement results presented in [4]. Only for a very small back volume (BC020) this behavior changes. Here, two peaks can be observed at approximately 115 Hz and 135 Hz. Also the peak at 300 Hz is significantly higher then those of the other back volumes. This can be explained by an increased effect of non-linearities in the air spring for small volumes [9].

Figures 7 and 8 show similar plots for 1.3 mm HPL and 2 mm Plexiglas membranes, respectively. Also in these plots it can be observed, that the lowest resonance peak is highly depending on the back volume, whereas peaks at higher frequencies are mostly independent of it. Again, the results for the smallest volume do not follow the general pattern. Furthermore, it can be observed that some of the absorption peaks disappear for the largest back volume (BC212) leaving only one resonance peak in the lower frequency range. Again this is caused by the systematic error which has been discussed above already.

Conclusion and Future Work

All in all, it could be shown that DMAs can provide effective sound absorption at more than on single resonance frequency. In fact, it was shown that especially for modes between 100 Hz and 200 Hz good absorption values can be reached at several frequencies. The absorption behavior here depends strongly on both the material of the membrane and the enclosed air volume. In general, some DMA configurations already reach almost the targeted absorption values at some frequencies, even if the membrane design is very simple at time.

For the future, further optimization is required in order to increase the number of modes in the target frequency range and to widen the absorption peaks to be less frequency selective. Additionally, the overall absorption is to be increased. To achieve these requirements, further membrane design ideas have to be simulated, manufactured and measured, such as using stepped or carved membranes, adding damping layers to the membranes, or by utilizing tuned-mass-dampers. Furthermore, the introduction of porous material into the back volume will increase the absorption performance of the DMAs.

In another future step, the passive DMAs will be enhanced by applying exciters in order to actively control the vibrations of the panels and hence to increase the performance of the absorbers even further.

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