Proceedings of 20th International Congress on Acoustics, ICA 2010

23–27 August 2010, Sydney, Australia

Improving transmission loss of light-weight panels by enhancement of skin tension through evacuation

Deborah Brosig (1), Volker Mellert (1), Hermann Remmers (2)

(1) Acoustic Department, Oldenburg University, Germany
(2) itap GmbH, Marie-Curie-Str. 8 Oldenburg, Germany

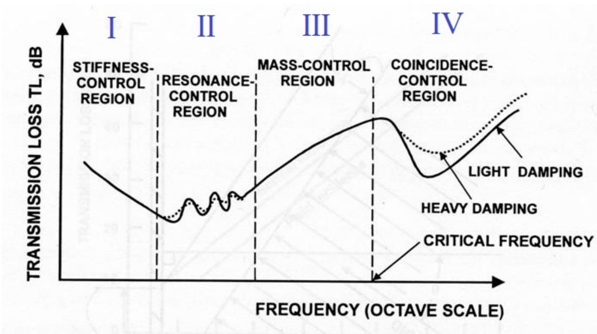
PACS: 43.20.El, 43.20.Ks, 43.20.Ye

ABSTRACT

Panels and walls within cabins of aircrafts and some other transportation means should have a low mass per area, which obviously leads to lack of transmission loss (TL). One way to improve the TL is to enhance the stiffness of the element, provided it is tightly fastened at its border strip. Experiments are reported by starting with usual honey-comb and similar air-tight panels, to which an appropriate light material of coarse-grained structure is added at one side of the surface. This structure is covered with a thin foil. The foil is stiffened by evacuating the added surface material, which leads to considerably stiffening of the complete device. An improvement of TL of 30 to 40 dB is achieved at low frequencies, depending on the TL of the untreated material. Constructions based on this principle are presented with measurements of the TL. The improvements and disadvantages with respect to resonant and coincident frequencies are discussed.

INTRODUCTION

Panel elements used in transportation such as the cabin of an airplane or a railway coach need to be light weighted but at the same time provide a high sound insulation as well as stability. Designing panels fit for these applications can be quite demanding since sound propagation is mainly governed by the so called "mass-law". Improving the perfomance of panel structures without an increase in mass is the objective of this paper.
In the context of this investigation, the frequency region of interest lies below the coincidence frequency (Parts I - III in fig. 1). In fig. 1 the behaviour of the transmission loss over frequency is shown. In part III the TL is proportional to mass per area. But increasing the stiffness in part I has the same influence as an increase in mass. By increasing the stiffness the resonance frequency in part II will be shifted to higher frequencies while the coincidence frequency (part IV) will be lowered. But since higher frequencies can be damped more easily by "classical" methods (porous absorbers, surface treatment,. . .), the principal focus will be on the lower frequency range. With the method suggested by Mellert et al. ([4]) the material is stiffened to increase the TL without an increase in mass.
Materials of interest are e.g. light weight honeycomb panels or fibre reinforced polymers as a core as well as extremely light weight additional materials which provides an increase in stiffness of the foil coating by their imminent structure.



Source: [2, Numbers added by author]

Figure 1: Exemplary curve of the behaviour of transmission loss with respect to frequency.

SETUP AND THEORY

The investigations are made in an impedance tube for frequencies between 100 Hz and 1200 Hz. The present investigation is made for plane wave incidence, since in an impedance tube of 100 mm diameter the first higher order modes occur above 1200 Hz. A loudspeaker is attached at one side of the impedance tube, the other end can be closed with different terminations. The loudspeaker radiates plane waves which are either reflected, absorbed or transmitted by the sample (see fig. 2). On either side of the sample two microphones register the sound pressure. The transmission loss is evaluated using the four-microphone technique as described in [1]. The setup is sketched in fig. 2.

Further explanation can be found in the next section.
For evaluation the software PULSE 11 by Brüel & Kjær is used. All samples are "evacuated" using either a water jet pump or a simple vacuum pump. Care is taken to reduce the noise from the pumps, which is radiated into the "silent" part of the impedance tube either by air or by structure-born sound. The acoustic dynamic range at low frequencies (about 100 Hz) is better than 70 dB at the receiving microphones on the "silent" side. All figures showing transmission loss were produced with MATLAB 2008.
The four microphone technique uses a plane wave ansatz. The solution of the differential equations then gives (compare the subindices to those in fig. 2)

$$\begin{pmatrix} p_{i,l} \\ p_{r,l} \end{pmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{pmatrix} p_{i,r} \\ p_{r,r} \end{pmatrix}. \quad (1)$$

The transmission loss in dB is then given by

$$TL = 20\, log|T_{11}|. \qquad (2)$$

Solving the equation in 1 requires two boundary conditions. For these measurements an anechoic and a reflecting tube ending are used. It would also be possible to use an open tube instead of a reflecting surface but the noise of the evacuation pumps has to be excluded.
From these two measurements with the sample and two measurements without sample (backround calibration) the transmission loss of the respective sample is computed.

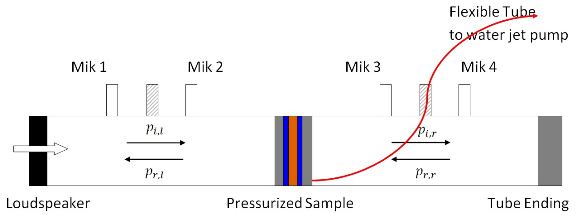


Figure 2: Setup: Sketch of the impedance tube equipped with a pressurized sample. The tube's inner diameter is 100 mm. 1/4 inch microphones are used.

Setup validation

To determine whether our measurement set-up yields reliable results it is tested with a simple aluminium sheet (DIN: EN AW 5754) of 1 mm thickness. According to [3] the transmission loss of this aluminium sheet is calculated for the case of a "simply supported disc" and measured. Equ. 3 shows the TL assuming the system to act as a simple damped harmonic oscillator (at fundamental mode), and using an adjusted loss factor δ.

$$TL = 20lg\rho c - 10lg[(\rho c + M\delta)^2 + (\omega M)^2 \cdot (1-(\omega_0/\omega)^2)^2] \qquad (3)$$

with

$$\begin{aligned} \omega_0 &= 2\pi 0.2287 c_L h/a^2 (\text{“simply supported disc” [3]}) \\ M &= \text{total mass} \\ h &= \text{thickness of disc} \\ c_L &= \text{longitudinal sound velocity of material} \end{aligned}$$

The measured TL of the investigated aluminium disc including the calculated TL (equ. 3) is shown in figure 3. As can be seen the two curves coincide nicely which proves the setup to be sufficiently acurate for our investigation.

The second setup for validating the measurements in the impedance tube consists of an arrangement of two aluminium discs (1 mm and 1.5 mm thick) with a gap of 12 mm between them. Variing the pressure inside the sample leads to considerable increase of TL at low frequencies and shifting of the resonance frequency of the assembly depending on the current pressure. As can be seen from the measurement in figure 4, rather strong fluctations in TL are observed at low frequencies. The origin is not fully clear, but is partly due to a lack of dynamic range on the "silent" part of the impedance tube.

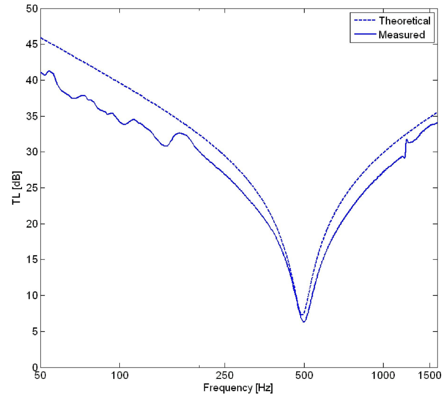


Figure 3: Measurement of TL of an aluminium sheet compared to the theoretical TL curve. The resonance frequency lies about 500 Hz. The curve was calculated using the ansatz for the simply supported disc (see 3).

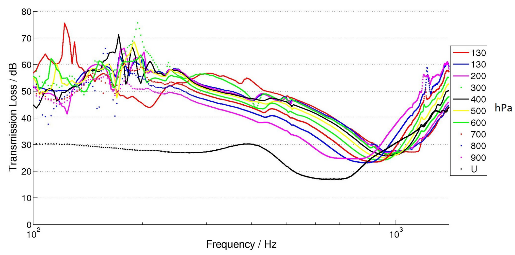


Figure 4: Measurement of TL of an two aluminium sheets with a 12 mm gap. The resonance frequency shifts with the different pressure values.

Sample setup I

To be able to measure de-pressurized non-airtight samples (porous materials,...) a device has to be constructed by which the air may be drawn from the sample. This is accomplished by using two PVC rings with an air outlet on one side and a thin Polypropylene (PP) foil on the other. The PP foils themselves do not contribute to the overall transmission loss, since their TL is negligible small. These rings are placed on either side of the sample, and via a flexible tube the air is sucked out. The foils get pressed towards the sample by evacuation. Since the samples sometimes have a rough surface, additional silicon rings are placed between PVC ring and sample to prevent leakage of air. Additional PTFE-tape is wound round the whole construction to ensure that no air passes the sample when inside the tube. An exploded sketch can be seen in fig. 5.

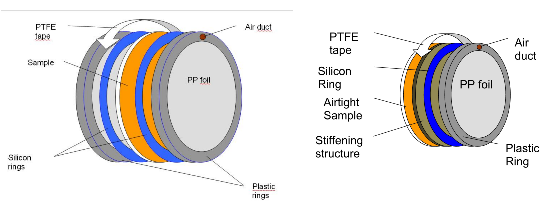


Figure 5: *left:* Exploded sketch of sample setup I, non-airtight materials enclosed in two rings covered with PP foils. *right:* Exploded sketch of sample setup II: airtight material with a layer of stiffening material against one used foil.

Sample setup II

For airtight samples (usually already rather stiff material) a second measurement series is conducted. Here only one PVC ring with foil is used on one side of the tested material. Between the ring and the sample a special material is additionally placed, which is designed only to stiffen the foil during pressurization. This setup is shown on the right hand side of fig. 5. Here the pressurization does not affect the material itself but *only* the extra layer and the foil. The goal here is to stiffen the foil by pressing against the extra layer thus producing a higher stiffness which results in a higher TL.

RESULTS

Results for non-airtight samples

One example of the first setup is a glas-fibre reinforced polymer. Holes are drilled into the surface of the material to make it permeable for air. The resulting increase in TL by simultaeously decreasing the mass (because of the holes) is shown in fig. 6.

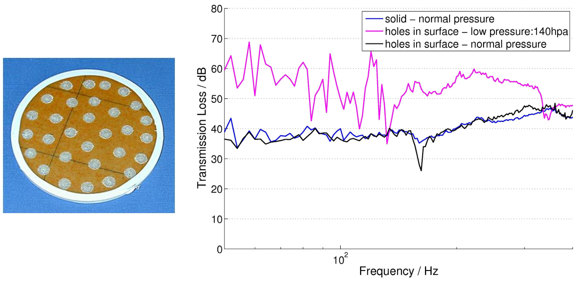


Figure 6: *left:* Photo of the glasfibre reinforced polymer with holes in surface. *right:* Results for pressurized samples: unmodified and with holes. You can observe the increase in transmission loss for the investigated frequencies (up to 400 Hz).

As can be seen the transmission loss increases for the pressurized sample. Materials that provide a rough surface nearly always increase in transmission loss. An example is following set-up with a natural fibre made from Hemp and PP fibres (50/50). This fibrous material can be pressed to various thicknesses to acieve different densities (and acoustic absorption loss). When put under evacuation with PP skins the TL is drastically increased: figure 7.

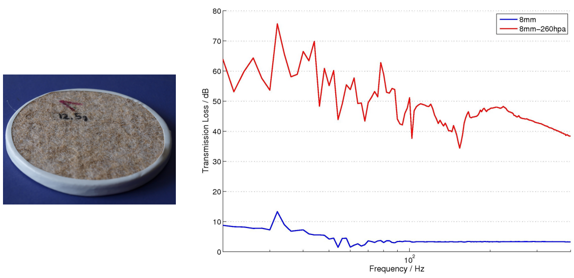


Figure 7: *left:* Photo of the natural fibre made from Hemp and PP. *right:* Results for de-pressurized samples of Hemp/PP of 8 mm thickness. A dramatic increase in TL is observed in the investigated frequency range (up to 400 Hz).

Results for airtight samples

For experiments with airtight samples an additional layer of a stiffening structure is applied. To demonstrate the improvement in TL a 10 mm honeycomb panel is combined with a Hemp-PP natural fibre material and then de-pressurized. Since the nomex honeycomb panel already features a stiff surface the simple treatment with additional PP skins does not produce any effect. But with the additional Hemp-PP stiffening structure an additional TL of 35 dB is gained compared to the combination unter ambient pressure and 5 to 10 dB with respect to the original honeycomb panel (see fig.8).

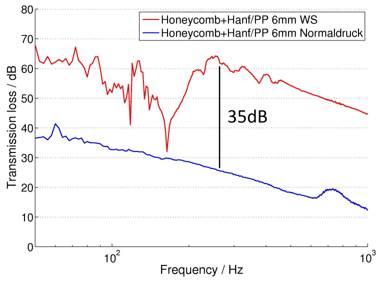


Figure 8: Transmission loss of a honeycomb panel of 10 mm thickness combined with 6 mm Hemp-Polypropylene panel as "support" for the PP-foil.

DISCUSSION

Non-airtight materials with a pronounced surface structure perform quite good under this new method. The additional stiffness provided by an air-tight foil as skin leads to a considerably higher TL below the resonance control region. For some materials the transmission loss can be increased by relatively low effort even combined with a decrease in mass.
Airtight materials which possess a smooth and stiff surface are not much affected by this treatment. However adding an extremely light structure which permits the foil to adapt under pressure to a "structured" surface increases the transmission loss.

OUTLOOK

For the future measurements in a TL test facility are planned, where samples of 1 m^2 will be investigated not only for plane waves but for statistical sound incidence using a reverberation chamber. This will also enable the testing of higher frequencies (above the coincidence region). Additionally a model for computing the transmission loss of various materials under this new method is in development.

REFERENCES

[1] B.H. Song, J.S. Bolton. A Transfer matrix approach for estimating the characteristic impedance and the wave number of limp and rigid porous materials. In *J. Acoust. Soc. Am.*, volume 107, 2000.

[2] D.A. Raichel. *The Science and Application of Acoustics*. AIP Press, 2000.

[3] T.D. Rossing, N.H. Fletcher. *Principles of Vibration and Sound*. Springer, 2004.

[4] V. Mellert, R. Kruse, H. Remmers. Improving transmission loss of light-weighted panels by increase of stiffness with an evacuated foil. In *DAGA Conference Proceedings 2009*, 2009.