# TRANSMISSION LOSS OF STRUCTURED SHEET METAL

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*In this paper measurements of the transmission loss of structured sheet metal and flat, unstructured sheet metal as reference are presented and differences are explained using the mode shapes of the sheet metal gained out of numerical calculation results. The measurements are performed in a window test chamber and the numerical results are obtained using the commercial vibro-acoustic solver FFT Actran. The measured transmission loss of the structured sheet metal shows a reduction within the range of about 5 to 12 kHz in comparison to the flat sheet metal. This behavior is discussed with regard to the modal density of the structured sheet metal. They vibrate in similar global modes as the flat sheet metals do, but for higher frequencies. Furthermore the structured sheet metals show unique local mode shapes due to the bump structure in comparison to flat sheet metals. These mode shapes and the higher stiffness give an explanation for the reduced measured transmission loss in the mentioned frequency range.*

## INTRODUCTION

By stamping regular bumps in components consisting of flat sheet metal the bending stiffness along different axes of the component can be increased and influenced specifically. Such structured sheet metals offer great potential in lightweight construction because of achieving similar bending stiffness with reduced material usage at the same time. The transmission loss of these structured sheet metals compared to flat sheet metals is of interest, because when being used in lightweight construction the material thickness and thus the mass per area is expected to decrease. This will have an adverse effect on the sound insulation. Moreover, a structured plate may have a bending stiffness that is not the same in all direction. A commonly used model for this is the orthotropic plate.

The transmission loss of an orthotropic plate is related to that of an isotropic plate, but with following differences: The orthotropic plate has two different bending stiffnesses, a maximum and a minimum corresponding to the orthotropic directions. This results in two different critical frequencies. For the transmission loss, this means that the frequency range with reduced sound insulation extends, in particular in between these two critical frequencies [1]. Structured sheet metals can have a number of structure variations. In this research the structure is a hexagonal regular bump structure with a small bridge of 2 mm between the bumps with a diameter of 33 mm. The thickness of the sheet metal is variable. During the manufacturing process by means of hydroforming from flat sheet metal to a structured sheet metal the material thickness is reduced particularly [2, 3].

## 1. MEASUREMENT OF THE TRANSMISSION LOSS

The measurement of the transmission loss of the flat and structured sheet metals were performed in a window test chamber based on the DIN standard 140–3 [4]. The sheet metals were fixed between two wooden plates of each 38 mm thickness as can be seen in Fig.1.

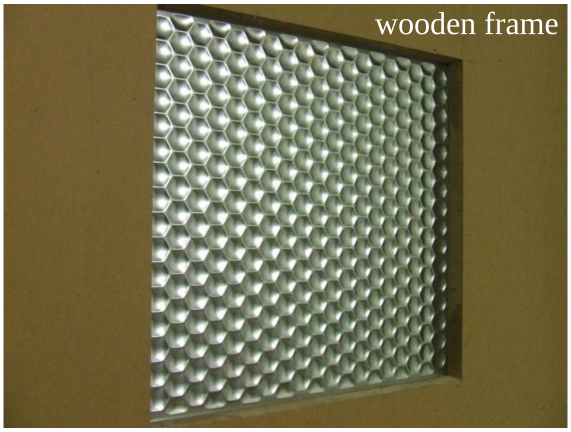


Fig.1. Structured sheet metal in a wooden frame during measurement, seen from the negative structured sheet metal side

Tab.1. Overview of measured steel configurations and color coding

| Steel | Thickness | Line color |
|---|---|---|
| DC01 | 1.0 mm | 🟦 |
| DC04 | 0.7 mm | 🟥 |
| DC04 | 0.5 mm | ⬛ |
| DX56D+Z | 0.5 mm | 🟪 |
| X5CrNi18–10 | 0.5 mm | 🟩 |

Five different sample combinations of steel alloy and sheet metal thickness were used in the measurements. From each of these configurations, a flat and a structured sample were tested (see Tab.1). As the structured sheet metals have two different sides, it is also of interest to analyze a possible directional dependence of the sound transmission. Thus, two of the samples were measured in both directions. The remainder was tested only for the sound transmission in one direction, where the convex side of the hexagonal bump structures was pointing towards the sending room. While this direction is referred to as "negative", the opposite direction with the convex side pointing to the receiving room is referred to as "positive" direction.

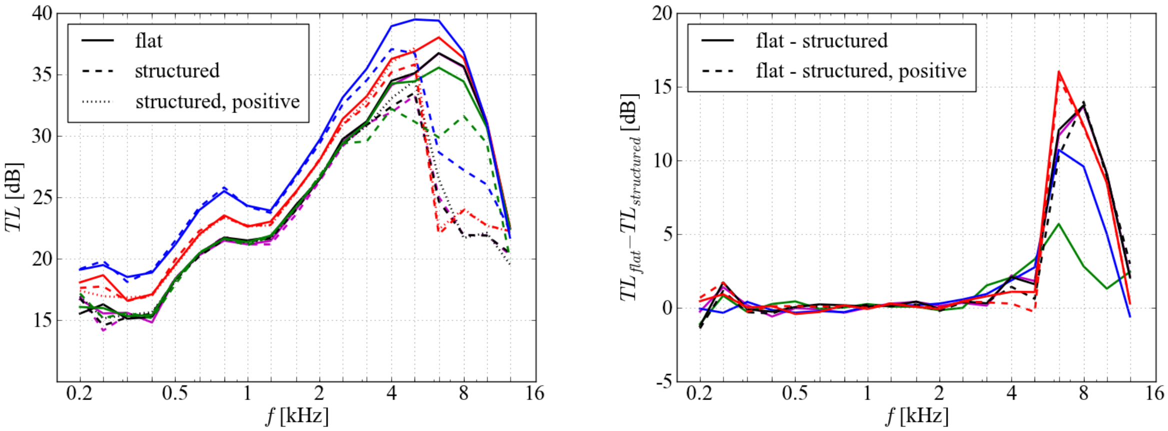


Fig.2. Measured transmission loss of all sheet metal configurations and differences between the flat and structured sheet metal transmission loss

The measurements were taken in one–third octave bands. The results for the diffuse-field transmission loss [5]

$$R = 10\,\lg\left(\frac{P_{incident}}{P_{transmitted}}\right)\,\mathrm{dB}$$

are shown in Fig.2. As expected from the mass-law theory of sound transmission [5], the transmission loss for the flat sheet metals increases with about 20 dB/decade below the coincidence frequency which is between 10 and 20 kHz for all samples tested. Moreover, in accordance with this theory the transmission loss increases with the mass per unit area as governed by the thickness of the plates.

If the structured and the flat samples are compared, there is a clear reduction of the transmission loss of the structured sheet metals from 5 kHz upwards up to about 12 kHz with a peak difference of about 15 dB compared to the flat sheet metals. The frequency range of the reduction seems to be independent from the sheet metal thickness. Concerning the orientation of the bumps there is no significant directional dependence of the transmission loss. The whole measurement campaign is discussed in more detail in [1].

## 2. NUMERICAL CALCULATION OF THE EIGENFREQUENCIES

To investigate the vibrational behavior of the structured sheet metals and a possible connection to the reduced sound transmission loss in the frequency range above 5 kHz, a numerical calculation of the eigenfrequencies was carried out. The commercial vibro-acoustic software FFT Actran was used and a plate modal analysis was performed. The analysis was based on CAD models of the flat and structured sheet metals. The models have the dimensions 587×587 mm, which corresponds to the opening area of the wooden frame in the window test chamber measurement and thus the area of the samples. The sheet metal CAD models were discretized using a finite element mesh, consisting of 2D first order shell elements, namely a mixture of triangles and quadrilaterals and bar elements at the boundary (Fig.3). It has a determined element length of 3 mm. Thereby a mesh resolution of about six elements per bending wave length was ensured. As the calculation should achieve results up to the frequency range of 12 kHz (according to a bending wave length of 19 mm for 0.5 mm or 28 mm for 1.0 mm sheet metal thickness), the element length of 3 mm was set. The mesh contains 47,800 elements for the structured sheet metal mesh and 38,400 elements for the flat sheet metal mesh.

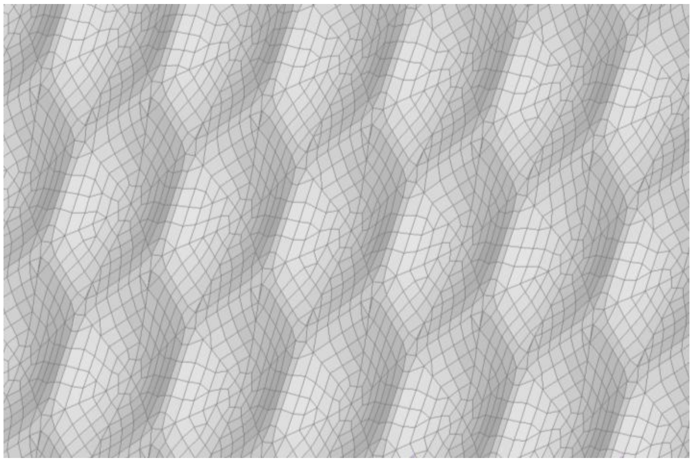


Fig.3. Finite element mesh, element length 3 mm

A plate modal extraction was performed to calculate the first 2000 modes, but limited to the frequency range from 1 Hz to 12 kHz. An isotropic solid material (Young-Poisson) with a Young modulus $E$ of 210,000 N/mm$^2$, a Poisson ratio $\nu$ of 0.31 and a density $\rho$ of 7850 kg/m$^3$ was used. The sheet metal was modeled as a thin shell with the respective thickness of each 0.5 mm, 0.7 mm or 1.0 mm. A displacement boundary condition was used with zero displacement in the normal direction of the sheet metal and free displacement in the other directions. The linear solver MUMPS was chosen. After finishing the calculations the result files containing the eigenfrequencies and mode shapes were exported and the modal density was derived.

## 3. RESULTS

Fig.4 shows the calculated modal densities for the flat and the structured sheet metals. For a flat plate there is an analytical result available for the modal density, where *N* is the mode count and *S* is the plate area [5]:

$$n(f) = \frac{dN}{df} = \frac{S}{d}\sqrt{\frac{3\rho(1-\nu^2)}{E}}$$

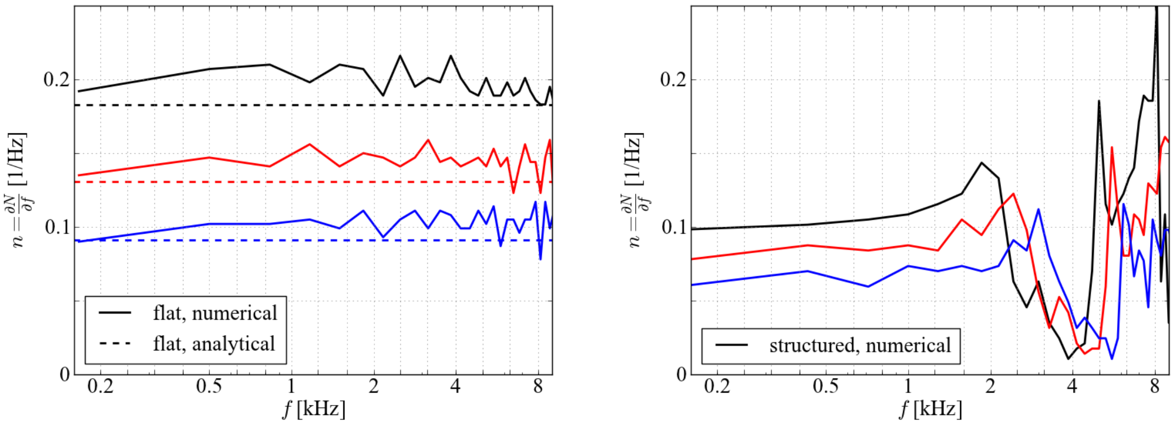
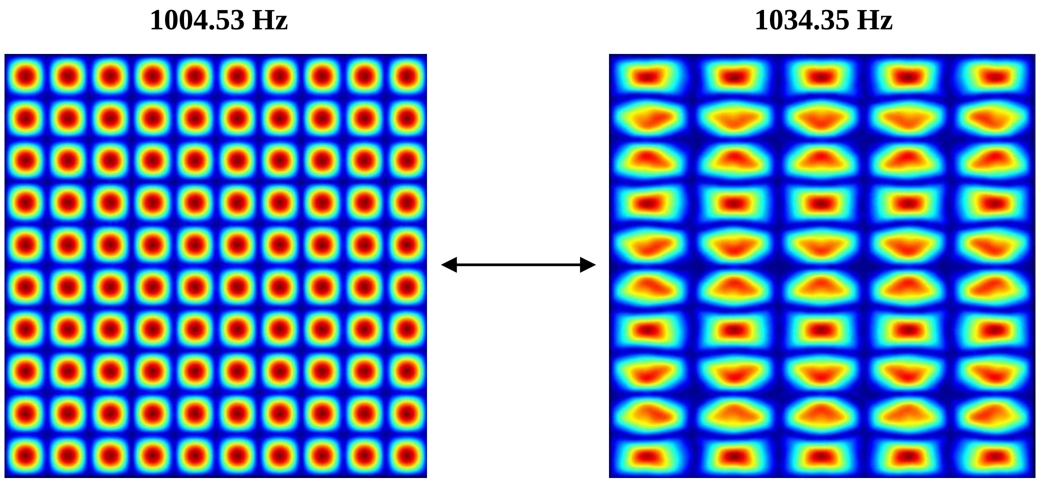


Fig.4. Modal density of flat (left side) and structured (right side) sheet metal (d= ▬ 0.5, ▬ 0.7, ▬ 1.0 mm)

The values are not frequency-dependent and are shown in Fig.4 (left side) for comparison. In the frequency range up to 1.6 kHz, the modal density for the structured sheet metal is also not frequency-dependent, but much lower than found for the flat sheets of same thickness and mass per area. This indicates a higher stiffness.


**1004.53 Hz**

**1034.35 Hz**

Fig.5. Mode shape of flat and structured sheet metal, thickness 0.7 mm, at approx. 1000 Hz, flat sheet metal (left hand) shows 10×10 mode, the stiffer structured sheet metal (right hand) shows 5×10 mode

As an example, Fig.5 shows a comparison between the mode shapes of flat and structured sheet metal with a thickness of 0.7 mm for a frequency of about 1000 Hz. The flat sheet metal vibrates in 10×10 mode and the structured sheet metal in the 5×10 mode, which corresponds to a lower mode number. The structured sheet metal vibrates in the 10×10 mode only at 1663.78 Hz. This demonstrates the lower mode density (Fig.4) or the higher stiffness of the structured sheet metal. The individual bumps of the structured sheet metal have less influence on the global mode shape for the lower frequency range. Above 1.6 kHz the 0.5 mm structured sheet metal modal density increases slightly and has then a minimum at 4 kHz.

For the thicker structured sheet metals these frequency regions are shifted slightly upwards because of the lower mode density. This frequency range corresponds also to the measured reduction in sound transmission loss. For higher frequencies the modal density increases again and is in the range of that of their reference flat sheet metals at about 8 kHz.

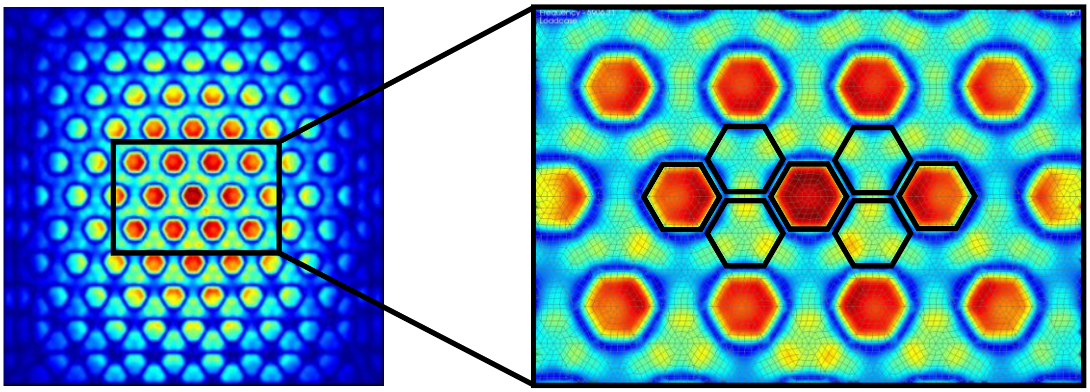


Fig.6. Mode shape of 0.5 mm thick structured sheet metal at 5906.31 Hz

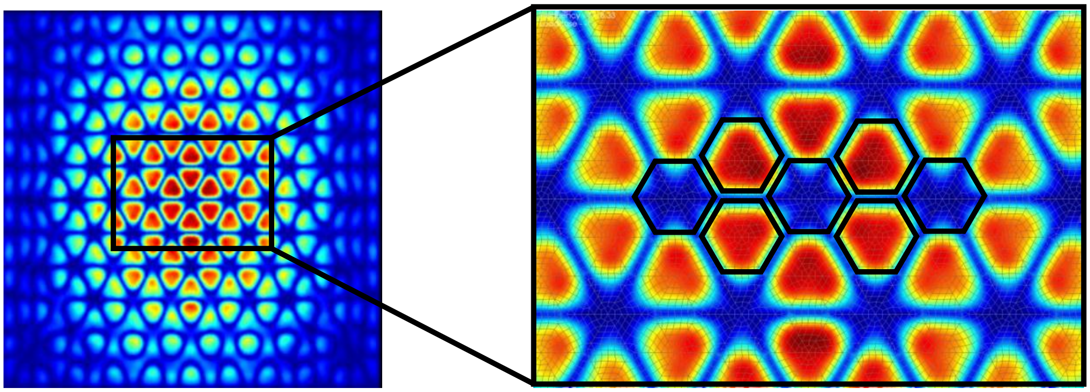


Fig.7. Mode shape of 1.0 mm thick structured sheet metal at 7718.33 Hz

In Fig.6 is shown the global and local mode shape of the 0.5 mm thick structured sheet metal at 5906.31 Hz. At this frequency range the measured transmission loss decreases significantly. It can be seen that the bumps vibrate locally, namely every second one in phase. These mode shapes distinguish the flat from the structured sheet metals as the flat ones cannot form such bump modes. The 1.0 mm thick structured sheet metal vibrates with a comparable mode shape at a frequency of 7718.33 Hz, caused by the lower mode density (Fig.7).

For large flat plates the transmission loss well below the coincidence frequency depends only on the mass per unit area $M$ ("mass law")

$$R_{mass\ law} = \left|20\,\mathrm{lg}\frac{\pi f M}{\rho_{air} c_{air}} - 3\right|\ \mathrm{dB}$$

and not on the stiffness. The transmission loss of a small plate, or a plate with stiffeners for diffuse sound incidence as assumed for the measurements can be assessed using [6]

$$R = R_{mass\ law} + \Delta R$$

with

$$\Delta R = \left(10\,\mathrm{lg}\,\rho_{air} c_{air}\sqrt{\frac{2}{\pi f d^3}}\sqrt[4]{\frac{12(1-\nu^2)}{E\rho^3}}\,a\right)\mathrm{dB},$$

where *2a* is the distance between the stiffeners. In the present case, there are no distinct stiffeners, but if *2a* is taken as a characteristic size of the stiffening structure, then for

$$\rho_{air} c_{air}\sqrt{\frac{2}{\pi f d^3}}\sqrt[4]{\frac{12(1-\nu^2)}{E\rho^3}}\,a < 1$$

the $\Delta R$ term becomes negative. If *2a* is assumed to be 35 mm, this is true for the whole frequency range, but becomes more important with increasing frequency. Thus, the observed reduction in sound transmission loss within the frequency range at about 4 to 8 kHz can be explained by the influence of the stiffening structure and its local modal behavior.

This work was supported by the Brandenburg Ministry of Science, Research and Culture (MWFK) as part of the International Graduate School at Brandenburg University of Technology Cottbus (BTU).

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