Sound Insulation of Foils and Membranes

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1 Introduction

Due to their small mass per unit area foils and membranes mostly have a much lower sound insulation than solid building elements. For that reason they are regarded as unsuited for noise prevention so that reliable acoustical data are often not available. On the other hand foils and membranes are increasingly used in lightweight architecture, for instance for the construction of tents or halls. Another new application are inflatable noise barriers [1]. For this range of application a detailed knowledge of the sound insulation is indispensible.

We investigated the sound insulation of a large number of foils and membranes, which differed by thickness and material [2]. The measurements were carried out on single as well as on double leaves. Apart from the sound insulation we also determined thickness, density and elasticity of the samples. This gave us the possibility to perform theoretical calculations and compare the measured and calculated results.

2 Samples

Our study included eight foils, fifteen membranes and seven double leaf constructions. The main properties of the samples are summarized in the following tables:

Type	Statistical value	Measured value					
		l	m''	ρ	E	f_g	R_w
Foils	Minimum	0,1	0,1	1160	6	324	2
	Maximum	1,0	1,6	2600	279	2368	18
	Mean value	0,4	0,7	1582	109	1305	10
Membranes	Minimum	0,2	0,2	927	187	38	6
	Maximum	1,5	1,9	2143	2110	633	19
	Mean value	0,9	1,2	1350	668	154	15

l thickness [mm]
m'' mass per unit area [kg/m^2]
ρ density [kg/m^3]
E modulus of elasticity [N/mm^2]
f_g critical frequency [kHz]
R_w weighted sound reduction index [dB]

Tab. 1 Description of the samples (single leaves).

No.	Construction				Acoustical properties			
	m'' for leaf		d	Absorption	f_r	R_w for leaf		
	1	2				1	2	1 + 2
1	1,4	1,4	100	without	230	16	16	17
2	1,4	1,4	0	without	230	16	16	17
3	1,6	1,6	100	without	210	18	18	23
4	1,6	1,4	100	without	220	18	16	18
5	1,6	0,2	100	without	420	18	6	18
6	0,2	0,2	100	without	560	6	6	8
7	0,2	0,2	100	with *	560	6	6	10

m'' mass per unit area [kg/m^2]
d distance between the leaves [mm]
f_r double leaf resonance frequency [Hz]
R_w weighted sound reduction index [dB]

* 20 mm mineral fibre in the gap between the foils

Tab. 2 Description of the samples (double leaves).

3 Experimental setup

The measurements were carried out in the building acoustical laboratory of the Fraunhofer-Institut für Bauphysik. The samples with dimensions of 0,8 m x 1,8 m were exposed to a diffuse sound field. We used third octave bands and a frequency range from 100 to 5000 Hz.

4 Theory

According to Tab. 1 the critical frequencies of all samples are much higher than the upper limit of the investigated frequency range. Therefore the transmission loss of single layers can be expressed with high accuracy by the mass-law of sound insulation:

$$R = 10 \lg \left[1 + \left(\frac{2 \pi f \, m'' \cos\vartheta}{2 \rho_L c_L} \right)^2 \right] \text{dB} , \qquad (1)$$

where ϑ is the angle of sound incidence and $\rho_L c_L \cong 400$ kg/(m^{2}s) denotes the characteristic acoustic impedance of air. With respect to the existence of a diffuse sound field we use $\vartheta = 45°$ in our calculations.

The transmission loss of double layers with low bending stiffness

$$R = 10 \lg \left[1 + \left(\frac{2 \pi f \, (m''_1 + m''_2) \cos\vartheta}{2 \rho_L c_L} \left\{ 1 - \frac{f^2}{f_r^2} \right\} \right)^2 \right] \text{dB} \qquad (2)$$

depends on the double leaf resonance frequency

$$f_r = \frac{1}{2\pi} \sqrt{s' \, \frac{m''_1 + m''_2}{m''_1 \, m''_2}} , \qquad (3)$$

where $s' = \rho_L c_L{}^2/d$ is the dynamic stiffness of the air gap and m''_1 and m''_2 are the masses of the two leaves. The frequency response of the transmission loss can be subdivided in three regions:

- For $f << f_r$ the system behaves like a single leaf with the mass $m'' = m''_1 + m''_2$.
- In the range of the resonance frequency $f \cong f_r$ a reduction of transmission loss occurs. The strength of the reduction depends on the damping of the system.
- For $f >> f_r$ we find an improvement of the sound insulation. The transmission loss increases by 18 dB per octave band compared to 6 dB per octave band in the case of single leaves.

Another effect which reduces the sound insulation of double leaves are resonances in the air gap. The first resonance occurs when the width of the gap equals half the wavelength in air:

$$f_g = c_L / (2d) \qquad (4)$$

For a gap width of d = 100 mm as in our experiments the resonance frequency is $f_g \cong 1700$ Hz.

5 Results for single leaves

For single leaves the transmission loss of all investigated samples reveals a similar frequency response. A typical example is shown in Fig. 1:

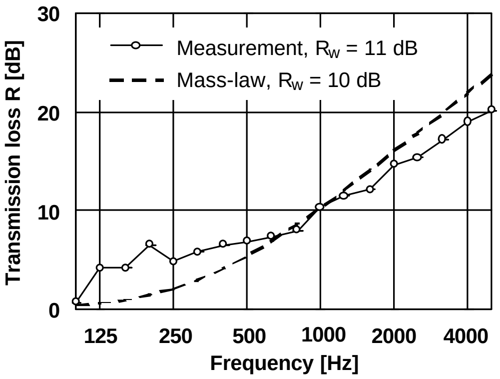

Fig. 1 Transmission loss of a foil with a thickness of 0,5 mm and a mass of 0,6 kg/m^2 as a function of frequency.

At low frequencies the measured transmission loss exceeds the mass-law, at high frequencies the curves run in reverse order. The point of intersection depends on the mass per unit area (for light samples the intersection shifts to higher frequencies) and lies between about 400 and 1600 Hz. Above the intersection the measured curve increases with a constant slope of about 5 dB per octave band instead of 6 dB per octave band predicted by the mass-law.

Since the deviations below and above the intersection partly compensate each other, the weighted sound reduction index R_w shows a relative good agreement with theory:

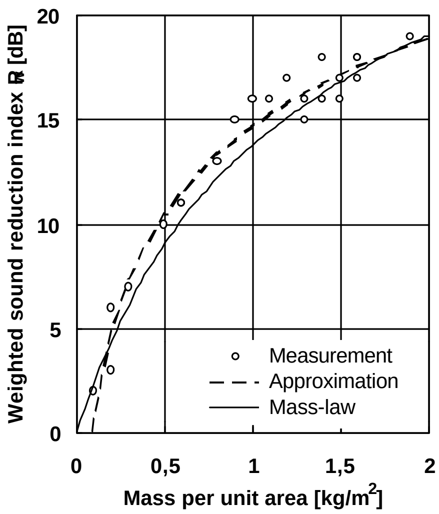

Fig. 2 Weighted sound reduction index of foils and membranes in dependence on their mass per unit area.

Figure 2 contains measured R_w-values, an numerical approximation of the experimental data and a R_w-curve according to the mass-law. The latter was produced by calculating R for several values of m'', determining R_w for each frequency spectrum and smoothing the R_w-curve to remove the 1 dB-steps resulting from the standardized weighting procedure. The numerical approximation is given by:

$$R_w = [14 \lg(m'') + 14{,}7] \text{ dB}, \quad (5)$$

where m'' has to be inserted in kg/m^2. Equation (5) describes the measured data with an error of maximal 2 dB.

6 Results for double leaves

As can be seen from Fig. 3 the acoustical behaviour of double leaf constructions consisting of foils or membranes differs considerably from theory:

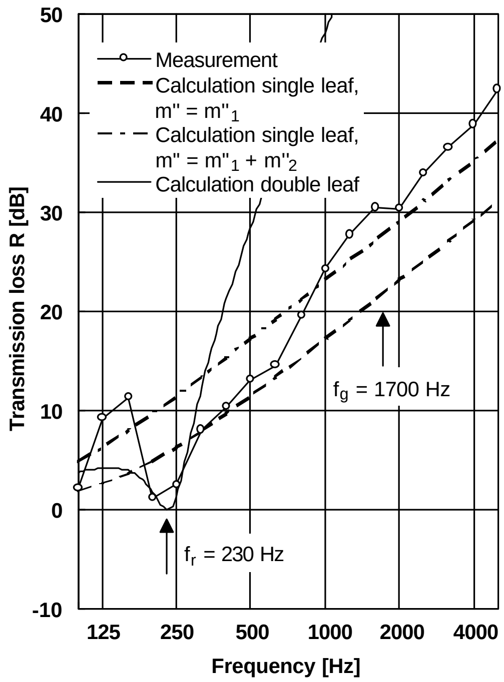

Fig. 3 Transmission loss of a double leaf construction consisting of two identical membranes with $m''_1 = m''_2$ = 1,4 kg/m^2 in a distance of 100 mm as a function of frequency.

Above the double leaf resonance frequency, which occurs at the calculated position, the measured transmission loss increases much slower than expected from theory. Instead like a double leaf the systems behaves more like a single leaf with the same total mass. The reason for this effect is so far not completely understood. Probably the additional mass of the air inside of the gap and the low bending stiffness of the leaves cause a change of the acoustical properties at high frequencies.

7 Summary

We investiged the sound insulation of several foils and membranes with m'' = 0,1 - 1,9 kg/m^2. The measurements were performed on single and on double leaves. Despite of systematic deviations in the frequency response the transmission loss of single leaves approximately corresponds to the mass-law. For exact predictions, however, the applied acoustical model must be improved.

The transmission loss of double leaves strongly deviates from theory. At high frequencies the structure behaves like a single leaf and not like a mass-spring-mass system. The reason for this effect has to be investiged in detail.

8 Literature

[1] Mehra, S. R.: Aufblasbare ultraleichte Schallschirme. Fortschritte der Akustik - DAGA 2001, S. 538 - 539.

[2] Müller, M.: Akustische Materialkennwerte und Luftschalldämmung von Folien und Membranen. Diplomarbeit, Lehrstuhl für Bauphysik, Universität Stuttgart (1998).