Experimental Investigations into Damping in the field of Building Acoustics

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Introduction

The Applied Acoustics Department of the Physikalisch Technische Bundesanstalt (PTB) Braunschweig, in cooperation with the Applied Mechanics Institute (InfAM) of the Civil Engineering Department of Braunschweig Technical University, is at present implementing a project funded by the Deutsche Forschungsgemeinschaft (DFG) to investigate damping influences in building acoustics.

It is the objective of this research project to analyze the effect of damping mechanisms on sound transmission in building construction. In particular, the influence on the measurement of sound reduction in the test stand will be investigated and a differentiation into properties of test object and test stand will be made.

Damping mechanisms

Generally speaking, damping means any loss of energy in an observed physical system. A system in building acoustics, in particular a wall test stand, comprises the fluid medium air, different solids, transitions between fluid and solid media as well as joints and junctions between solids. At each of these points, energy can be irreversibly converted.

Whereas the physical causes of **airborne sound insulation** are known to such an extent that they can be calculated with sufficient accuracy for all environmental parameters in a wide frequency range [1], the damping effects which are possible in different **solids** are manifold. This is why the description is limited to the phenomena, e.g. in visco-elastic n-parameter models. At the **boundary layer** between solid and air, partial reflection, impact noise radiation and airborne sound damping occur. Mere **joints** at first only show reflection and waveform conversion. At these points, different materials are mostly connected by adhesion, screws or mortar. In addition to typical joint effects, such **junctions** show friction at the connecting layers.

A system in building acoustics thus normally shows a number of damping mechanisms which are to be investigated separately to be able to qualitatively and quantitatively predict them for a given system. It is the aim of the project to separate the effects by combining numerical FE and BE calculations and measurements on scale models and to evaluate their influence.

Model scaling

In a system in building acoustics, not only the airborne sound fields but also the dispersive impact noise fields and the transitions between solid and fluid media are to be taken into account. For scaling of airborne sound and impact noise, the similarity invariant Helmholtz number He is used. At air/solid transitions, the ratio of impact noise wavelengths and airborne sound wavelengths must be invariant. To scale damping in the system, the radiation damping with the invariant radiation loss factor η_s and the internal material damping η in the formulation of the complex modulus are examined.

The scaling regulations found in the course of these examinations can be subdivided into those concerning the geometry and those concerning the model material. In the following, the index "O" stands for the full-scale and the index "M" for the model scale. "n" is the scale factor.

Geometrical scaling:

$$L_M = \frac{1}{n} L_O \qquad (1)$$

$$h_M = \frac{1}{n} h_O \qquad (2)$$

Scaling of the material properties:

$$\left(\frac{E}{\rho\,(1-\mu^2)}\right)_M = \left(\frac{E}{\rho\,(1-\mu^2)}\right)_O \qquad (3)$$

$$\frac{\rho_M}{\sigma_M} = \frac{\rho_O}{\sigma_O} \qquad (4)$$

$$\eta_M = \eta_O \qquad (5)$$

Frequency scaling:

$$f_M = n \cdot f_O \qquad (6)$$

where L is a characteristic length, h the plate thickness, E the Young's modulus, ρ the density, μ the Poisson number, σ the radiation efficiency, η the internal material damping and f the frequency.

Due to frequency scaling, the material properties with the above conditions must be scaled in addition from the original to the model frequency range:

$$A_M(f_M) = A_M(n \cdot f_O) = A_O(f_O) \qquad (7)$$

Here, A stands for a material property or a combination of properties.

Material selection

If the regulations found are strictly applied to the material selection, a material must be found whose internal damping, density and Young's modulus are identical with the original material. This means that the same material is used for the model and the original. Because of (7), the properties of this material must be frequency-independent. As conventional materials do not meet this requirement, a compromise has to be found which at least appropriately scales the most important properties. In this case, it must in addition be possible to simulate the model with sufficient accuracy and relatively low effort by numerics. This is why the model material must above all be homogeneous and isotropic.

A material often used in modelling are laminated fiber sheets (e.g. MDF). It has, however, turned out that the structure of this material is not isotropic as a result of the manufacturing process. This is why cast acrylic glass, which is isotropic and can relatively easily be processed, was selected. Moreover, its properties meet the scaling requirements as far as the size is concerned.

		Lime sand brick	Concrete	Acrylic glass	
Young's modulus	E	~ 3	2 .. 20	3 .. 6 *	10^9 N/m^2
Density	ρ	900 .. 2200	1400 .. 1700	~ 1180 *	kg/m^3
Damping	η	~ 0,02	~ 0,02	0,01 .. 0,07*	1
Sound velocity	c_L	2000 .. 3000	1200 .. 3400	1600 .. 2300*	m/s

Table 1: Comparison of typical properties of lime sand brick, concrete and acrylic glass (* values from measurements performed at PTB, others taken from the literature)

Material investigations

For the numerical calculation, the dynamic properties of the materials used in the model must be known. This is why the density, the isotropy, the dynamic Young's modulus and the damping of the acrylic glass used were determined. Figure 1 shows real parts and imaginary parts of the Young's modulus between approximately 30 Hz and 6 kHz determined on a bar. Up to now, 15 kHz have been reached using small strip samples.

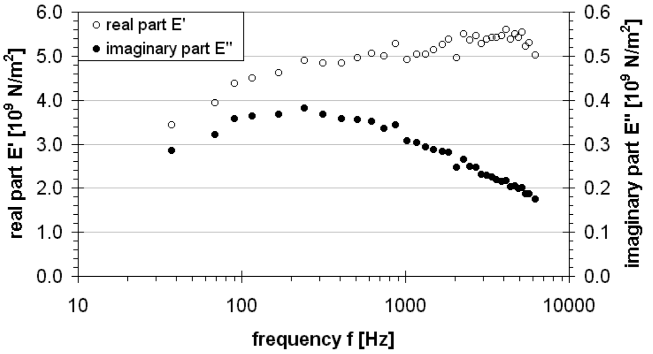

Figure 1: Real part and imaginary part of the Young's modulus of acrylic glass. Real part and damping were measured as a function of the frequency and the imaginary part was derived from them. The density was determined to be 1180 (±75) kg/m^3.

Model investigations

For practical reasons, 1:10 ($n = 10$) was selected as the model scale. The exterior walls of the model test stand are made of acrylic glass and are 25 mm in thickness, which corresponds to an original wall with a thickness of 25 cm. The dimensions of the model follow the wall test stand available at the PTB and standard EN ISO 140-1: 1997 [4]. For validation of the numerics, a thin partition wall of acrylic glass, (thickness: 3 mm) with rigid connection was inserted to achieve a low airborne sound insulation and a defined connection of the partition wall. Junction point damping was deliberately avoided. The model is carried on six rubber feet and thus isolated from the surround.

Due to the strong air absorption at high frequencies, the airborne sound decay time decreases in the model from approx. 1 s at 1kHz to 0,5 s at 5kHz and to approx. 0,1 s at 40kHz. Figure 2 shows sound transmission losses measured on the model.

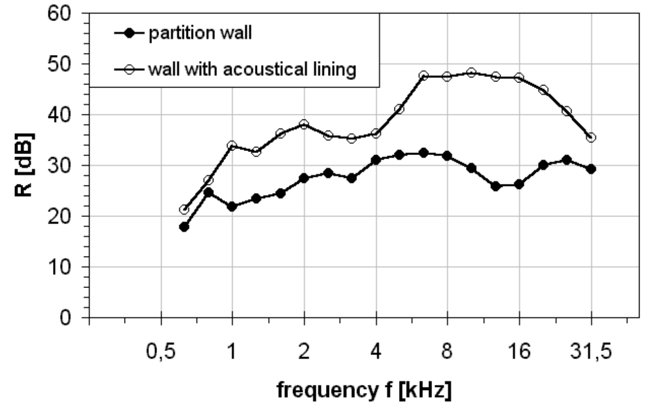

Figure 2: Airborne sound insulation on the idealized test stand model on a scale of 1:10 a) with a partition wall of acrylic glass, 3 mm in thickness b) additionally with acoustical lining, 22 mm air gap and 19 mm MDF. The model is isolated from the surround.

Outlook

At present, further models with modified connection and different partition walls are in preparation. Determination of the dynamic material parameters will be extended to cover higher frequency ranges and the accuracy will be improved.

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