Zukunft Bau

SHORT REPORT

Title

Transmission-loss enhancement of building components (walls, ceilings, facades) by a new action principle applicable to new and old buildings

Motivation

Resonance effects can deteriorate the sound transmission loss of building components at low and medium frequencies (50 Hz to 500 Hz) significantly, e.g. of double-leaf plasterboard walls (Fig. 1). Conventional strategies like raising the damping or shifting the resonance frequency to even lower frequencies did not result in solutions which are acceptable also with respect to space requirements, weight and costs.

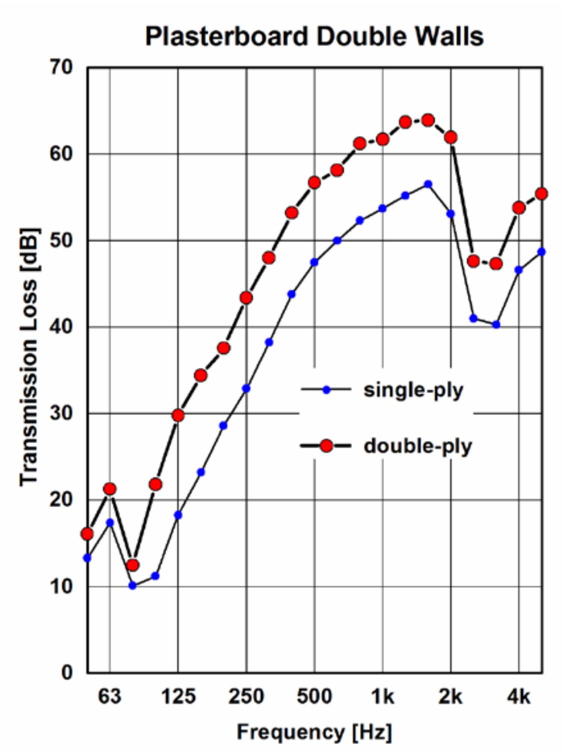

Fig. 1: Measured transmission loss of single-ply and double-ply plasterboard cavity walls. © Fraunhofer IBP

Subject of the research project

The basic idea is the following: The transmission loss of a building component shall be improved not mainly by reduction of vibration, but by reduction of radiation into the receiving room or – equivalently on the sending-room side – by reduction of the excitability due to airborne sound. The Russian acoustician Stepanov realized this "action principle" by a checkerboard-like arrangement of flat resonators on a plate. Radiation was into half-space. Radia-

tion reductions of the order of 10 or 20 dB could be achieved both theoretically and experimentally; however, as often with resonance phenomena, there are also deteriorations. Apparently, this principle has not been applied in building acoustics so far. It is the objective of the project to investigate its potential and applicability with respect to sound reduction.
The first task was retracing and analyzing the theoretical statements of Stepanov in detail and transferring them to the sound reduction case. In a transmission-loss measurement the building component does not radiate into a half-space, but into a cuboid-shaped room. This requires a completely different description. Actually, one should work with the acoustic modes of the receiving room, a rather laborious job. As an alternative, a simplified model was developed which should be sufficiently accurate, when a clear enhancement is achieved. This model considers the radiation into a semi-infinite duct. Since it is not meant to calculate the transmission-loss, but only its enhancement, i.e. a difference, its prediction potential is raised considerably.
Assuming that the building component vibrates like a rigid piston, it can be determined by a simple equation which duct mode should be excited in order to arrive at a certain sound pressure level drop below a given frequency. Then the needed size and number of resonators is deduced. Limitation to a two-dimensional formulation facilitates analytical calculations and visualization of results. This simplification favors comprehension of the problem, which is rather unfamiliar in building acoustics. On the other hand, computations of the three-dimensional airborne sound field were carried out only numerically by the COMSOL software, however, also with simplifications and specializations, e.g. to normal sound incidence and certain boundary conditions.
In reality a wall does not vibrate like a piston, but in its eigenmodes. In the two-dimensional model this was accounted for by a given half-cosine-shaped velocity distribution, corresponding to the assumption that the "wall" vibrates in its fundamental mode. For the "acoustic short circuit" to work, the resonators must be sufficiently small, such that neighboring checkerboard squares on the bare wall have nearly equal velocity amplitudes (Fig. 2). This is an additional condition for the maximal size of the resonators.

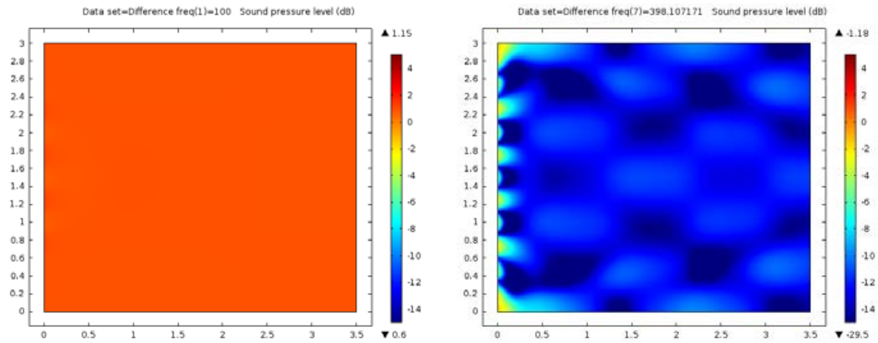

Fig. 2: Calculated sound pressure level distribution (red: high; blue: low) in a duct at 100 Hz (left) and at 398 Hz (right). Half-cosine shaped excitation modified by seven resonators at left end; right end without reflection. © Fraunhofer IBP

The assumption that the wall vibrates in its fundamental mode does not always apply at the frequency of the transmission loss dip, in particular when – like in the last series of measurements – the double-leaf resonance was shifted to higher frequencies by reducing the plate distance. The bending-wave field on the wall is then characterized by wavelengths which are smaller than the wall dimensions. Then the maximally "allowed" resonator size becomes even smaller.
Finally, there is another complication: the change in the wall vibration caused by the attached resonators. The wall becomes heavier, locally stiffer and more damped. This change can lead to a further tightening of the condition for the resonator size.

Fig. 3: Resonator arrangement "8|8" on 1.5 mm thick steel plate with 25 cm edge length (orange: resonators; black: bare plate). © Fraunhofer IBP

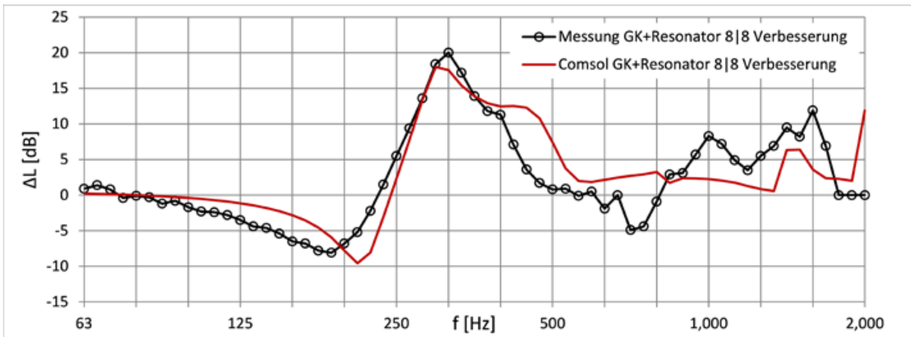

Fig. 4: Sound transmission loss improvement of a steel plate in a duct with 25 x 25 cm² cross-section by resonators in arrangement "8|8" (see Fig. 3); measured values (circles) and prediction with COMSOL. © Fraunhofer IBP

The theoretical and numerical investigations were accompanied by numerous measurements in an impedance duct (Figs. 3 and 4) and in the testing facilities for windows and doors (Figs. 5 and 6). The "spring" of the resonator consisted of a soft elastic material (Sylomer), its "mass" of aluminum or steel sheet.

Fig. 5: Plasterboard with 56 resonators (1.5 mm steel on 25 mm Sylomer, edge length 10 cm) in the opening of the door testing facility. © Fraunhofer IBP

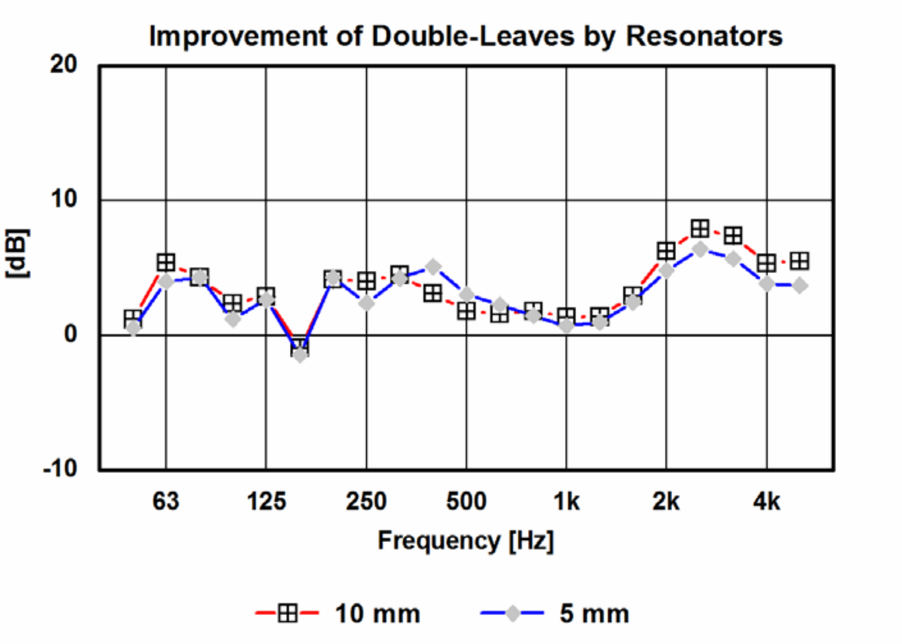

Fig. 6: Sound transmission loss improvement of double-leaf cavity walls (cavity depths 10 mm oder 5 mm) by resonators measured in the door testing facility (averages over both measuring directions). © Fraunhofer IBP

Conclusion

- The desired effect was experimentally verified: improvements up to 20 dB or 9 dB for normal or diffuse sound incidence, respectively.
- With smaller resonators higher improvements could have been obtained also for diffuse sound incidence.
- The agreement between predicted and measured improvements was satisfactory.
- Practical resonators of the construction type pursued here could not be tuned to resonance frequencies around 40 Hz.
- The effect does not depend on the measuring direction.
- The effect occurs in a similar manner when the resonators point to the cavity, i.e. act inside the cavity of the double-leaf wall. This opens new vistas.

Project data

Short title: Radiation reducers for improved sound transmission loss

Researcher / Project management: Prof. Dr. Waldemar Maysenhölder

Total cost: 135 000 €

Public funding: 90 000 €

Project duration: 24 months