Short version of the report on the R&D project

Absorption of low frequency impact sound by Helmholtz resonators integrated in the air volume of timber beam floor constructions

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1 Introduction

Low frequency impact noise below 100 Hz is the dominant contribution to what people hear from walking persons on timber floor constructions. Furthermore timber floor constructions tend to vibrate more strongly compared to concrete floors, due to their small mass per unit area. Often wide- spanned floors are used in public and industrial buildings, which are even more sensitive to low-frequency vibrations. In fact one may assume that the low frequency eigenmodes also cause or at least contribute to low frequency impact noise. The two effects should therefore not be treated separately.

As an example figure 1 shows the 1/3-octave spectrum of a timber floor construction with a normalized impact sound level Ln,w of 41 dB and a spectrum adaptation term CI,50-2500 of 6 dB. The construction can certainly be considered as well- performing as far as impact sound is concerned. The measurement was carried out when a male person (75 kg) was walking in socks at a speed of 100 steps/min, pursuing a track of an “eight” on the floor with respect to a minimum distance of 70 cm from the walls. Additionally, the hearing threshold at low frequencies according to the German standard DIN 45680:2004 is added. It is obvious, that the residual contribution to the total walking noise is dominant in the frequency range from 40 Hz to 100 Hz.

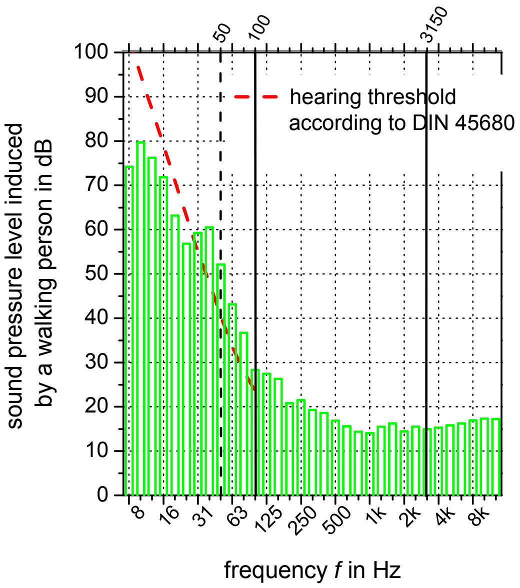

Figure 1: Sound pressure level induced by a walking person on a timber floor construction with Ln,w = 41 dB; indicated in red is the hearing threshold according to DIN 45680. Residual noise originates in the frequency region between 40 Hz and 100 Hz.

Among typical constructional measures to reduce low frequency noise like increasing the mass per unit area or stiffening the construction, two measures based on their intrinsic resonant behavior have been investigated.

As far as timber joist constructions are concerned, the air volume between the beams contributes to the transfer of low frequency impact noise. The air volume can be regarded as a pressure chamber at low frequencies due to its small dimensions. Helmholtz resonators installed there and tuned to the frequency range between 50 Hz and 100 Hz are supposed to absorb the sound transmitted and therefore reduce low frequency impact noise.

For the damping of low frequency vibrations in the range of 10 Hz to 70 Hz, measurements with tuned mass dampers have been carried out. Investigations have shown, that the eigen-frequencies of timber floor constructions do not necessarily overlap. Therefore tuned mass dampers can be designed and located at the antinodal points of the eigenmodes in order to strongly damp the movements of the floors.

2 Helmholtz resonators in timber joist constructions

Construction and integration

Figure 2 shows the principle of the integration of a Helmholtz resonator in the air volume between the beams as well as two out of 16 tested variations of implementations of Helmholtz resonators.

In order to achieve a high degree of absorption, the volume of the resonator should be large. In our investigations the Helmholtz resonators were made of a single gypsum board (thickness t = 12,5 mm). The inner dimensions were chosen to 105 cm x 42 cm x 14 cm (V = 60 l). As mouth geometry a single slit of a width of 10 mm in the middle of one plate, parallel with the longer side of the resonator box, was used. Many parameters had been tested in advance in a diffuse sound field by measuring the transfer function H(f) using two microphones, one inside the resonator and one outside in the diffuse field. The tuning of the resonance frequency was done by adapting the length of the slit. Figure 3 shows the calculated resonance frequency according to a well-known formula and using end corrections Δt according to Mechel or Fasold.

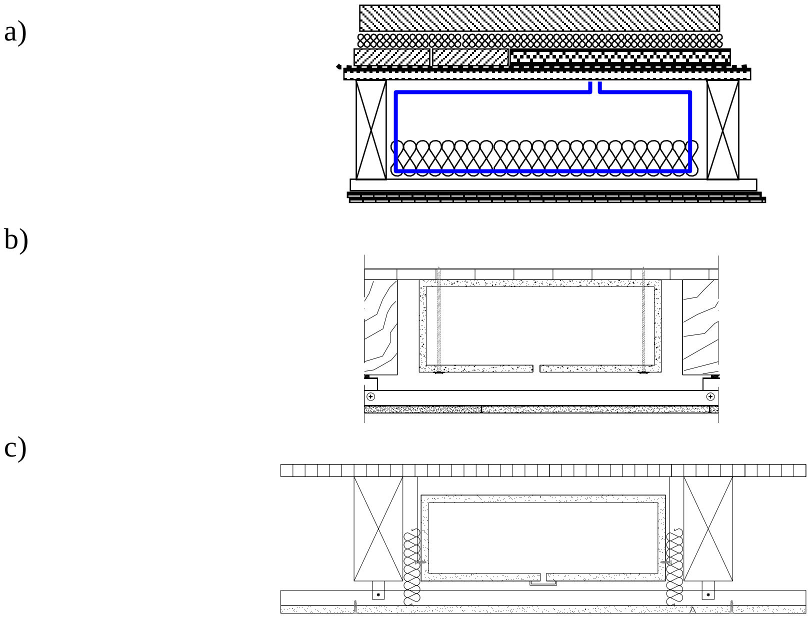

Figure 2: a) Sketch of the integration of a Helmholtz resonator (in blue) in an timber joist construction with a suspended ceiling, an ad-ditional mass layer and a floating floor. The mouth of the resonator is coupled to the inner air volume. b) Integration of the resonator by screwing it to the top layer of the static construction. The layer of the additional mass and the floating floor is not shown in this picture. c) Integration of the resonator by suspending it by threads; additionally, mineral wool as damping of the air volume between the joist was added.

Usually the formulas are based on the assumption that dimensions are small compared to the wave length at resonance frequency. Due to constructional reasons and the goal to maximize the volume this assumption does not hold for the resonators used, especially for the length l of the slit. Therefore an empirical correction (see equation 1) of the geometrical cross section area of the slit S_{geo} was added, taking into account the ratio of the slit length and the wavelength at resonance frequency, was added. For the dimensionless parameter κ a value of 1.25 was chosen.

$$f_0 = \frac{c_0}{2\pi} \cdot \sqrt{\frac{S}{V \cdot (t + 2 \cdot \Delta t)}} \qquad S = S_{geo} \cdot \left(1 - \kappa \cdot \frac{l}{\lambda}\right) \qquad (1)$$

The width of the resonance of the Helmholtz resonators turned out to be much more than could be expected on the basis of calculations quoted in literature. Typically, the full width at half maximum (FWHM) of the resonance reaches values of approx. 10 Hz. Therefore each 1/3-octave band in the frequency range from 50 Hz to 100 Hz can be influenced by one tuned Helmholtz resonator.

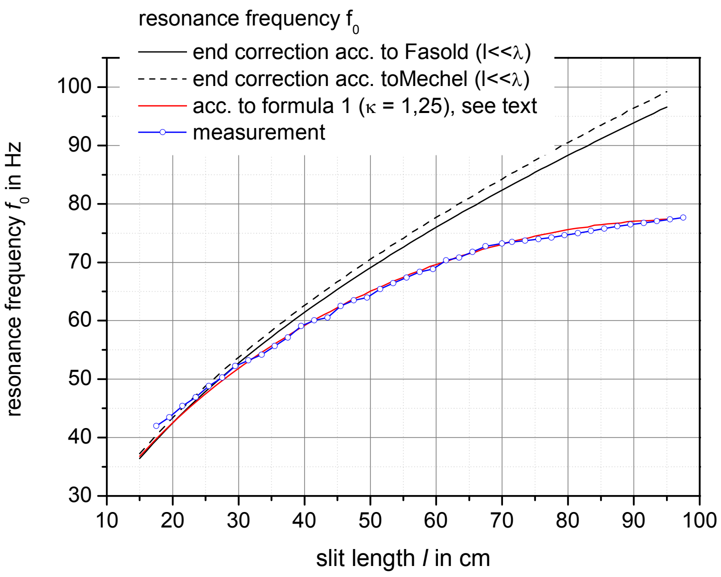

Figure 3: Resonance frequency of a box-shaped, slit-type Helmholtz resonator (V = 60 l)

Results on the reduction of impact sound

Due to the assembly procedure of the Helmholtz resonators the construction of the suspended ceiling had to be changed several times. This usually influences the single number values for the impact sound and the sound reduction index. Therefore a comparison of impact sound levels for the different constructions is not recommendable. Instead, the comparisons in the next figures show the individual construction with active and inactive (by taping the mouth) resonators.

The Helmholtz resonators did not show any effect on reverberation time in the receiving room. Therefore impact sound levels instead of normalized impact sound levels are displayed in the figures. Figure 4 shows the impact sound levels for the system sketched in figure 2 b). As expected, a clear decrease in the impact sound levels in the frequency range of 50 Hz to 100 Hz can be seen. A total of 21 Helmholtz resonators had been mounted in the air volume between the joists. The sum value of Ln,w and CI,50-2500 decreased by only 1.3 dB. This is due to the fact that this single value is of course a result of the behaviour also in the frequency range from 100 Hz to 3150 Hz, which is not influenced by the Helmholtz resonators.

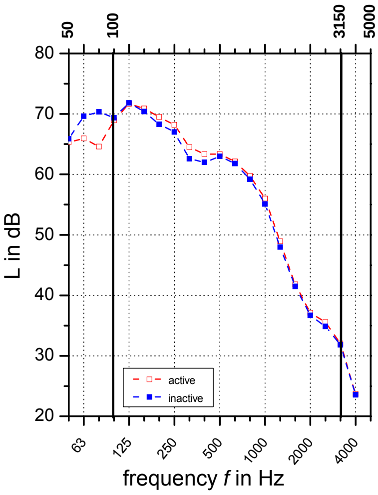

Figure 4: Impact sound level of the construction shown in figure 2 b). The two curves show the situation with either active or inactive Helmholtz resonators. The 21 resonators were tuned to resonance frequencies of 53, 65, 78 and 94 Hz. The effect of the resonators in this frequency range is obvious.

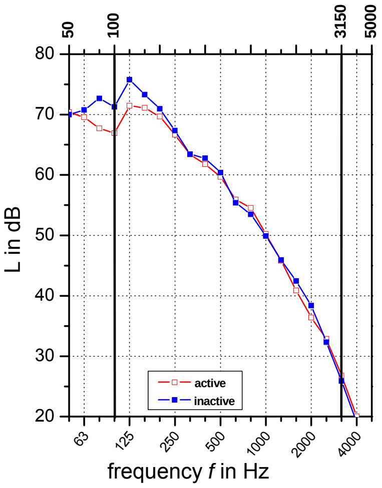

Figure 5: Impact sound level of the construction shown in figure 2 c). The two curves show the situation with either active or inactive Helmholtz resonators. The 21 resonators were tuned to resonance frequencies of 50, 63, 80 and 90 Hz. The effect of the resonators in this frequency range is again obvious. Due to an additional eigenmode of the bottom plates of the resonator boxes at approx. 120 Hz there is an improvement of the impact sound insulation in the frequency range above 100 Hz.

In figure 5 the same comparison is shown for a set of 21 Helmholtz resonators (differently tuned compared to the ones in figure 4) in the construction shown in figure 2 (bottom). The improvement on impact sound transmission extends to frequencies of 160 Hz. This might be due to the fact that the bottom plate of the resonators could vibrate freely due to the type of mounting.

Measurements have shown that the bottom plate has its fundamental frequency at appr. 120 Hz and is obviously excited as well. The eigenmode acts as an additional absorber. The sum value of Ln,w and CI,50-2500 for this construction decreases by 3,1 dB when the resonators are active.

Figure 6 shows the comparison of the sound levels induced by a walking person in socks on the construction of figure 2 c). The difference between active/inactive resonators amounts to 10 dB in various 1/3-octave bands (use right axes of the figure).

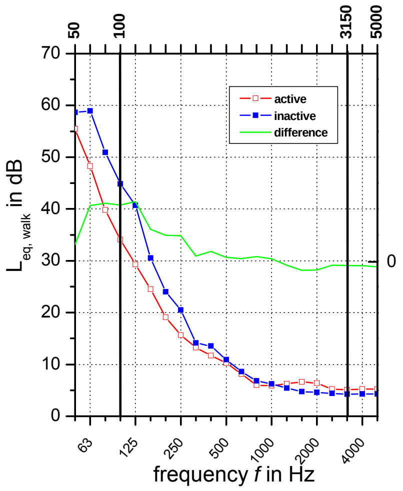

Figure 6: Sound level induced by a walking person on the construction shown in figure 2 c). Improvements of 10 dB in various 1/3-octve bands have been measured.

3 Conclusion

Helmholtz resonators have the potential of absorbing much of the low frequency impact sound transmitted through the air volume between the beams of a timber joist construction. The resonance frequency can be tuned to sufficient accuracy; for each 1/3-octve band a separately tuned resonator is needed. Construction and mounting is rather easy. Nevertheless a detailed analysis of the interaction between air volume, damping material inside the air volume and the resonator is still necessary in order to optimize the behaviour.