Alternative Determination of Dynamic Stiffness of Thick Insulating Layers

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Introduction

The dynamic stiffness of insulating layers is a decisive parameter for the sound insulation of multi-layer building components such as floating floors, additional linings and external thermal insulation composite systems (ETHICS). With restriction to (mostly thin) layers of insulating materials used under floating floors a measurement procedure is regulated in the standard DIN EN 29052 [1]. This restriction and some other reasons require a reliable procedure applicable for insulating layers in other constructions. For example, the dynamic stiffness of very thick layers of ETHICS is hard to analyse. The contact conditions, e.g. contact stiffness by surface roughness, adhesive, plugs etc., can strongly influence the results. These phenomena cannot be determined in detail and the measurement uncertainty is generally high.

Conventional measurement

One of the measuring arrangements proposed in [1] is shown in Fig. 1a. A mechanical force (sinusoidal, noise, pulse) is used to excite the resonance system comprising the test specimen, which is protected (foil) and plastered (gypsum) to get a plane interface to a standardised mass (plate).

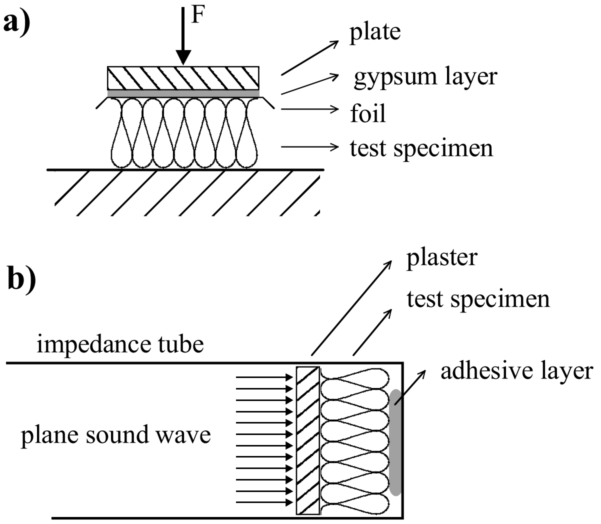

Figure 1: Measuring setup for determination of dynamic stiffness of an insulating layer (test specimen), a) according to [1] (example), b) by using an impedance tube [2].

Though this measuring setup is very similar to a real floating floor, some secondary effects are assumed to be of minor influence. The bulk stiffness s' of the insulating layer can be regarded as a combination of material stiffness s'_M with the stiffness of internal air s'_A (in open or closed cells) in parallel and with the contact stiffness s'_C (surface roughness on both sides) in series connection. A simplified electro-mechanical notation (without mass and damping) could be:

$$s' = \frac{1}{\frac{1}{(s'_M + s'_A)} + \frac{1}{s'_C}} \qquad (1)$$

Especially the contact stiffness may cause differences between the measurement result of s' and its effect in a practical application. In this context it should be considered that in the measuring setup the insulating layer is pressed on a plane base plate, whereas in practice (e.g. of ETHICS) there is an adhesive layer of certain thickness between wall and insulating material. However, also within the laboratory method some problems could arise from contact stiffness if very thin insulating layers have to be analysed. An exemplary calculation shall illustrate the relation between measured and real stiffness of a material with a Young's modulus E = s' t = 2 MN/m² (layer thickness t) and with a quite high contact stiffness of 100 MN/m³. Two graphs of stiffness versus layer thickness are shown in Fig. 2. The first graph is calculated without any contact stiffness and the second one with the mentioned value.

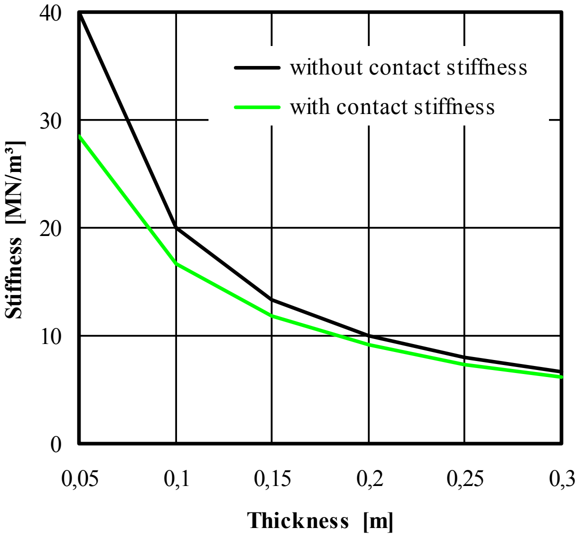

Figure 2: Layer stiffness versus layer thickness of an insulating material (E = 2 MN/m²) without any contact stiffness and with s'_C = 100 MN/³ calculated by following eq. (1).

As expected the influence of the contact stiffness decreases for increasing layer thickness. Therefore very thick layers should not be analysed by using thinner slices of the specimen without quantifying the contact stiffness and correction if necessary.

Alternative measurement

In comparison with the standard shaker excitation, which is far from reality of thermal insulation systems, an airborne sound excitation has several benefits. Regarding the plane wave excitation as a special case the impedance tube represents such a measuring setup as shown in Fig. 1b. The measured sound absorption reveals the resonance behaviour of the mass-spring system, Fig. 3. Further practical conditions are ensured by horizontal orientation of the multi-layer system and by definite lateral terminations with suppressed energy flow even for very thick specimens. Moreover, the influences of different fixing or support systems, e.g. adhesives, plugs or frames, can be investigated in impedance tubes with large cross-sections (> 1 m²).

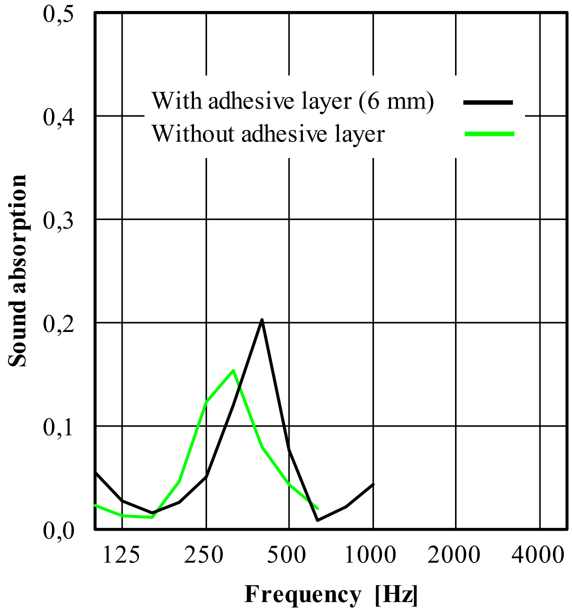

Figure 3: Measured sound absorption of an ETHICS (4 mm plaster, 100 mm polystyrene) for two types of fixing (without and with partially applied adhesive of 6 mm thickness) on the hard back wall of the impedance tube.

With the known mass per unit area m'' the dynamic stiffness can be easily derived. For the system presented in Fig. 3 (m'' = 6.6 kg of the plaster) the determined stiffness without adhesive layer was 23.5 MN/m³ and with adhesive (6 mm thick, 50 % of the area) 35,7 MN/m³. The dynamic stiffness of the polystyrene boards measured acc. to [1] was 37.1 MN/m³. In order to assess these results the measured sound reduction of the same ETHICS on a heavy wall (approx. 350 kg/m²) is shown in Fig. 4. The minimum caused by the mass-spring resonance appears in the range between 315 Hz and 400 Hz in accordance with the sound absorption maximum in Fig. 3. Though the simulation of the fixing (adhesive) parameters did not fully succeed the actually known influence [3] is outlined by the absorption measurements.

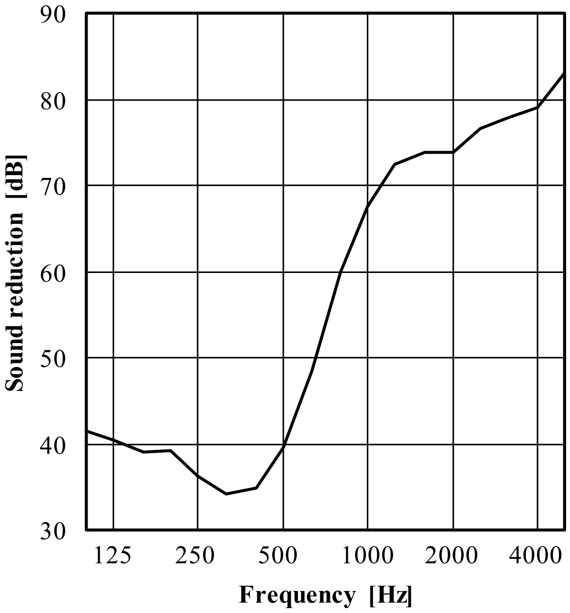

Figure 4: Measured sound reduction (acc. To DIN EN ISO 140-3) of the ETHICS as used in Fig. 3 on a heavy wall.

In this case the deviation of the differently determined stiffness values might be of minor relevance. But for another example, an additional lining comprising 50 mm polystyrene and 12.5 mm gypsum board, the difference was given by 31 MN/m³ (impedance tube) and 69 MN/m³ (acc. to [1]). The sound absorption maximum as well as the sound reduction minimum have been measured at 315 Hz (1/3 octave band), so that the conventionally determined stiffness is far to high.

Summary

The impressive potential of the alternative stiffness measurement in an impedance tube has been demonstrated. For analysis of the relevant (vibro-) acoustic parameters of materials and systems there are impedance tubes of different cross-sections available (from 0.2 m x 0.2 m up to 1.7 m x 0.65 m). Hence this method is an useful instrument for applied research, e.g. on acoustical optimisation of ETHICS. Nevertheless, the standard procedure [1] should not be replaced but revised to reduce the inherent measurement uncertainty.

References

[1] DIN EN 29052-1: Acoustics; Determination of dynamic stiffness; Part 1: Materials used under floating floors.

[2] DIN EN ISO 10534: Acoustics; Determination of sound absorption coefficient and impedance in impedance tubes.

[3] Weber, L., Brandstetter, D.: Uniform acoustical dimensioning of external thermal insulation composite systems. Research report B-BA 6/2002, Fraunhofer-Institute for Building Physics, Stuttgart (2003).