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INTERLABORATORY DYNAMIC STIFFNESS MEASUREMENT OF EXPANDED POLYSTYRENE.

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ABSTRACT

As a framework of the research in the ETICS (external thermal composite insulation composite system) influence on the sound insulation of walls, an apparent dynamic stiffness (s'_t) interlaboratory measurement was performed in accordance to the standard EN 29052-1 [1]. Measurements were performed on samples of Expanded polystyrene (EPS), a closed cell material. Generally, three excitation approaches (pulse- hammer hit; white noise and sine signal- shaker excitation) were used. The significant differences in results were measured not just in comparison between laboratories but also between measurement approaches. The differences up to 169% were found between results for specific specimen.

INTRODUCTION

In building acoustics, structure borne sound insulation plays important role. The usual way to improve the structural borne or impact noise sound insulation of constructions, is to use appropriate designs of construction details, the use of dilatations (mechanical separation) and the use of appropriate material properties. One of the basic examples is a floating floor. In case of floating floors, the impact noise insulation is determined by a massive part and elastic medium placed upon the floor construction. In engineering practice, the properties of elastic layers are defined by the dynamic stiffness s ($MN.m^{-3}$). The dynamic stiffness is defined as the ratio of the dynamic force to the dynamic displacement. The standard EN 29052-1 [1] specifies a method for determining the dynamic stiffness of materials intended for floating floors. However also airborne sound insulation can be affected by the elastic properties of used layers. A good example is a wall with an external thermal insulation composite system (ETICS). ETICS consists of a thermal insulation layer placed on the outside of the walls of a building and covered by a thin solid layer (typically plaster), which offers an adequate solution against thermal loss, involve a low installation cost and easy to apply. Compared to the original acoustic insulation spectrum of the bare wall, the insulation spectrum after application of ETICS shows a dip around the mass-spring-mass (m-s-m) resonance frequency of the two ETICS layers, due to the thin solid layer acting as a responding mass, and the thermal insulation layer as spring [2-14]. Also in case of ETICS the spring mechanical properties can be characterized by dynamic stiffness. One of the approaches is using the same measurement technique as for floating floors case (EN 29052-1), which will be discussed in this paper. In respect to the ”papabuild” project (Advanced physical-acoustic and psycho-acoustic diagnostic methods for innovation in building acoustics, H2020-MSCA-RISE-2015), the framework research is focused also in the ETICS sound insulation. An extensive dynamic stiffness measurement campaign of 76 thermal insulation samples was done (this campaign, however, is not objective of this paper). The round robin test from 2016 [15] proved that there are significant differences in measurement results when measuring in accordance to EN 29052-1. Also unneglectable differences in results related to the way of excitation were found [16]. Motivated by this knowledge, samples EPS (Expanded polystyrene) material based were chosen to be measured in three different laboratories. Chosen laboratories were:

- Laboratory of Acoustics (KU Leuven, Leuven, Belgium)
- Laboratory of Acoustics (A&Z Acoustics s.r.o., Bratislava, Slovakia)
- Laboratory of Acoustics (TGM, Wien, Austria)

TESTS EXPLANATION

The method of the standard EN 29052-1 determines the dynamic stiffness by measuring the resonance frequency f_r of the fundamental vertical vibration of mass-spring system where the mass is a steel plate (massive plate placed on the top of the specimen, consisting of a layer of EPS with a thin layer of plaster on top; see for instance Fig 1c). The total mass (usually steel plate + layer of plaster) is usually around $m_t \approx$ 200kg.m^{-2}. The spring-element is the elastic EPS material under test. The standardised result obtained, for sample of 0.2x0.2m, is named the apparent dynamic stiffness, s'_t (MN.m-3) (eq.1), where m'_t (kg.m^{-2}) is total mass per unit area of the test specimen *and* f_r (Hz)is extrapolated resonant frequency.

$$s'_t = 4\pi^2 \cdot m'_t \cdot f_r^2 \qquad (1)$$

The closed cell thermal insulation material EPS (ρ=20kg.m^{-3}) with thicknesses of approximately 20, 50 and 140mm was chosen for measurements. “Vibration of the load plate only” measurement method as one of the most frequently used method was used. However two different excitation ways were used (excitation by pulse signal, white noise or sine signal). Pulses were generated by instrumented laboratory hammer and white noise and sine signal excitation by shaker with white noise generator. Both laboratories had their own hardware specifications of measurement setup. General principles are shown on figure 1.

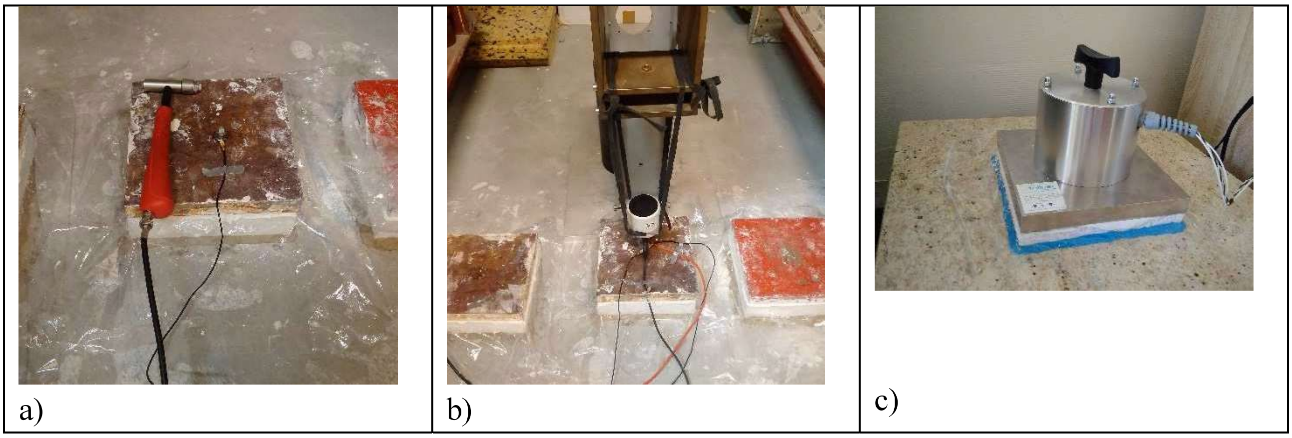

Figure 1 a) The pulse excitation measurement setup; b) White noise excitation measurement setups; c) Sine signal excitation measurement setup DYPS.

The measurement setups can be divided to three groups:

- The pulse excitation measurement setup. Setup was built from B&K accelerometer and Endevco instrumental hammer. Measurements were driven by Matlab routine connected to hardware via Roland doucapture-ex DAQ.
- White noise excitation measurement setups. Setup was built from B&K Shaker, impedance head and power supply. Measurements were driven by Matlab routine programed based on impulse response method. Computer and all hardware were connected by Roland doucapture-ex DAQ.
- Sine signal excitation measurement setup DYPS [17]. Is the compact measurement system with Software (Fellner company)?

Because of measuring the closed cell material, the joint between the specimen and the base was sealed around the perimeter with a fillet of sealant.

Results

All measurement results were collected and compared (see Table .1). The column „m_t“ gives the measured mass per unit area of the applied layer of plaster. The eigenfrequency of the mass-spring system was determined from the measured transferfurnction between the acceleration and force sensors. This eigenfreuqency is mentioned in the column „f_r“. The apparant dynamic stiffeness is computed from equation (1) given above, and is listed in the column „s'_t“. The mean values were calculated per each sample, laboratory and excitation method. Unfortuanty, not all samples and methods were used in both laboratories:

Laboratory no.1: Just specimens of thicness 0.02 and 0.14m were measured by pulse excitation and specimen of thicnkess 0.02 by sine signal excitation.

Laboratory no.2: Specimens of thickness 0.02, 0.05 and 0.14m were measured under sine signal excitation.

Laboratory no.3: Pulse and white noise excitgation approach was used for both samples.

Some deviation in laboratory resulst was expected in advance. As is mentioned in [15], there are examples, where dynamic stiffness measurements of the exactly same specimen performed in the same laboratory and by the same measurement approach obtained different results up to about 55% of deviation. It shows how sensitive is measurement approach on the boundary conditions of the sample. Also the precission of plaster layer and sealant material application can influence the measurements, resulting in a deviation up to 300%. The mean values of s'_t are compared in the figure 2.

Table 1 Coupled result of apparent dynamic stiffness measurements;

Lab./ meth./vol./*d*(m)	m_t (kg.m^{-2})	f_r (Hz)	s'_t (MN.m^{-3})	Lab. / meth./vol./*d*(m)	m_t (kg.m^{-2})	f_r (Hz)	s'_t (MN.m^{-3})
Lab_1/pulse/1/0.02	181.5	106	80,50	Lab_3/pulse/3/0.02	197.5	128	127,70
Lab_1/pulse/1/0.14	191.89	64	31,00	Lab_3/pulse/1/0.05	196.25	91	64,10
Lab_1/sine/1/0.02	191.97	142.5	153,90	Lab_3/pulse/2/0.05	202.5	85.8	58,80
Lab_1/sine/2/0.02	193.19	79	47,60	Lab_3/pulse/3/0.05	213.75	93.8	74,20
Lab_1/sine/3/0.02	192.09	80.3	48,90	Lab_3/pulse/1/0.14	222	63.8	35,60
Lab_2 sine n./1/0.02	203.72	141	159,90	Lab_3/pulse/2/0.14	201.25	64.2	32,70
Lab_2/ sine n./2/0.02	203.86	136	148,80	Lab_3/pulse/3/0.14	200	67.6	36,00
Lab_2/ sine n./3/0.02	203.69	131	138,00	Lab_3/white n./1/0.02	217.5	104.4	93,50
Lab_2/ sine n./1/0.05	203.76	107	92,10	Lab_3/white n./2/0.02	198.75	123.4	119,40
Lab_2/ sine n./2/0.05	203.87	108.3	94,40	Lab_3/white n./3/0.02	197.5	124	119,80
Lab_2/ sine n./3/0.05	203.84	107.5	93,00	Lab_3/white n./1/0.05	196.25	93.38	67,50
Lab_2/ sine n./1/0.14	203.36	71.2	40,70	Lab_3/white n./2/0.05	202.5	84.63	57,20
Lab_2/ sine n./2/0.14	203.5	71	40,50	Lab_3/white n./3/0.05	213.75	94.75	75,70
Lab_2/ sine n./3/0.14	203.75	72	41,70	Lab_3/white n./1/0.14	222	64.38	36,30
Lab_3/pulse/1/0.02	217.5	101.2	87,90	Lab_3/white n./2/0.14	201.25	62.25	30,70
Lab_3/pulse/2/0.02	198.75	128.2	128,90	Lab_3/white n./3/0.14	200	67.88	36,30

Also in our case, results obtained based on pulse excitation shows slightly lower values in comparison to the shaker excitation (Lab_1/pulse and Lab_3/pulse). The resonance peak is dependent on the force applied on the specimen. Force amplitude applied in case of pulse excitation is higher in comparison to shaker excitation case. Shaker excitation resonance frequencies are moreover extrapolated to the theoretical Force F=0N. This procedure is not done in case of hammer excitation. Also nonlinearities in dynamic response of specimen occurs in case of hammer excitation. All of this causes the differences between shaker and hammer excitation results. However there are significant differences also in case of just shaker excitation results comparison. For example in shaker excitation measurement of 20 mm thick EPS sample, the resulting s'_t deviates from 83.47 to 148.9 MN.m^{-3}. This unneglectable difference between different laboratory measurement results was probably caused by a variation of measurement conditions due to the mounting of the specimens.

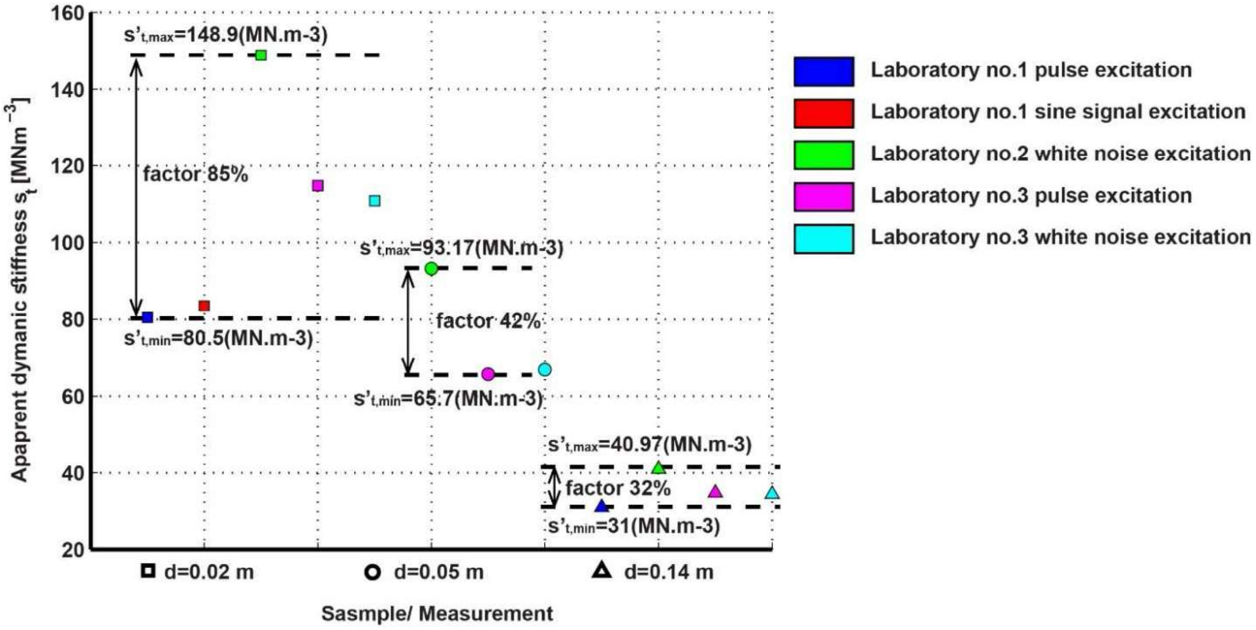

Figure 2 The comparison of mean resulting values of ***s'$_t$*****;**

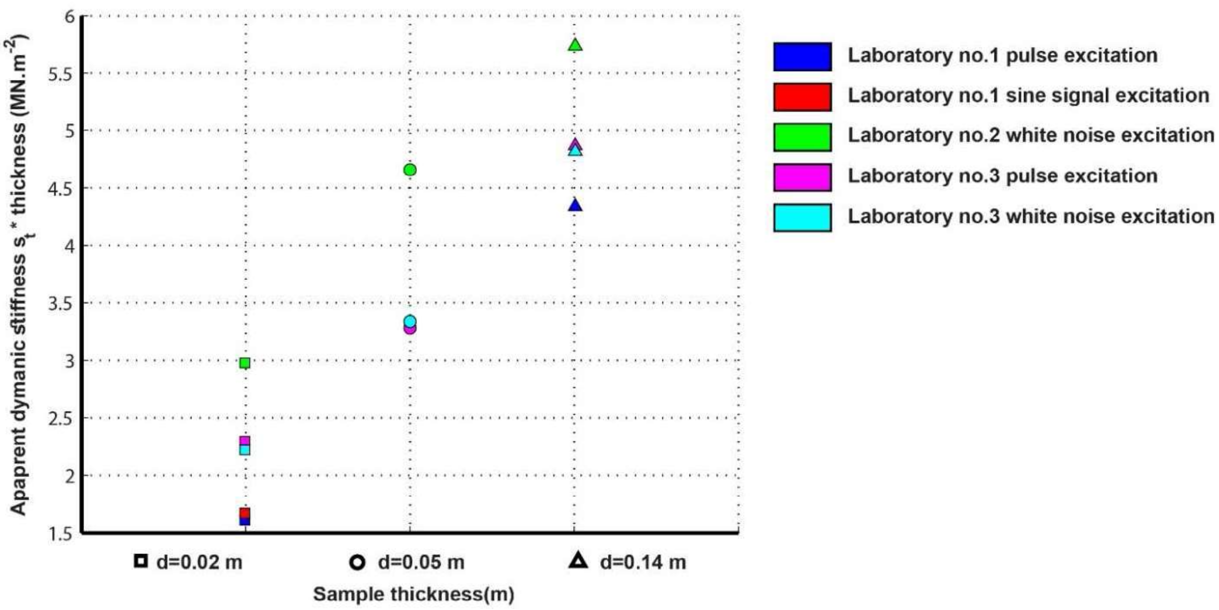

Figure 3 The apparent dynamic stiffness multiplied by thickness of the specimen;

The thickness of the sample has an influence, on the apparent stiffness in N/m^3. In the figure 3 show the results obtained after multiplying the stiffness *s'$_t$* by the sample thicknesses. The thus obtained results from laboratory no. 3 are systematically highest and results obtained from laboratory no.1 the lowest. Interestingly, if we compare the deviation between shaker and hammer excitation just for specific laboratories separately, deviation is not that big.

Conclusions

The apparent dynamic stiffness interlaboratory measurement was performed. Measurements were focused on testing EPS material samples. Generally, three excitation approaches (pulse- hammer hit; white noise- shaker and sine signal- shaker excitation) were used. The significant differences in measurement results were obtained. Both the measurement results between the laboratories differed, as well as between measurement approaches used. It appeared that the differences between the laboratories are more significant as compared to the differences between measurement approaches (e.g. hammer versus shaker excitation). The differences in the measurement results between the laboratories can probably best be explained by the way the specimen was fixed (the plaster and sealant). The (less significant) differences between the measurement approaches can be explained by an uncontrolled force amplitude of hammer excitation and nonlinearities in the dynamic response of specimen in case of hammer excitation.

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