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EXPERIMENTAL DETERMINATION OF ACOUSTIC BEHAVIOR OF BUILDING MATERIALS BY MEANS OF ACCELEROMETERIC MEASUREMENTS

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In Central Europe, brick blocks with incorporated system of voids ensuring good thermal properties are widely used in the building industry. In the present, increasingly higher acoustic load gains on importance especially in the surroundings of places with high traffic load, places close to the airports or in urban areas. This fact should be taken into consideration in the design of constructions in order to ensure their good acoustic performance. The very first step of such design lies in the experimental determination of acoustic properties of the reference construction elements which are, if necessary, subsequently optimized by adjustment of the voids volume and geometry or filling of the voids by various bulk fillers ensuring a higher level of scattering of the propagating acoustic signal. In this paper, steel prism and brick block were subjected to measurements by accelerometers in the frequency range 1 – 10 kHz in order to compare acoustic behavior of materials with a significantly different structure. Finally, frequency-dependent displacements in accelerometers position, important input parameters for successive modeling, were calculated and compared.

Keywords: Acoustic attenuation, Lossy media, Accelerometer, Displacement, Brick block, Steel.

1 INTRODUCTION

Acoustic properties of building materials needs to be taken into consideration in the design of constructions due to in-time increasing amount of man-produced acoustic load (Gupta *et al.* 2018). High acoustic load is especially present and negatively affecting life in urban areas, places close to main thoroughfares and airports. It was proved that that high level of noise negatively influences human well-being and health, e.g. in terms of long-term stress, diabetes (Sorensen *et al.* 2013) or cardiovascular diseases (Babisch 2014). Comprehensive research dealing with adverse effects of environmental noise and road traffic noise on human health were published e.g. by Munzel *et al.* (2018) or Paiva *et al.* (2019). Due to a high impact of noise on human health, attention is devoted to appropriate urban planning, which is one of the key factors reducing the level of noise in living areas. Gozalo *et al.* (2013) analyzed urban noise by means of continuous equivalent sound level in 27 cities in Spain, Chile and Portugal in order to prove that such analysis can be used as a tool for urban planning and for designing sound pollution prevention policies. Similar research was conducted by Gozalo *et al.* (2015) in 21 locations in Madrid.

In addition to well defined urban planning policies, attention must be paid to a proper design of building structures in terms of acoustic performance and selection of building materials with good acoustic properties. It is evident that experimental determination of acoustic parameters is a crucial factor in such process. In the present, evaluation of acoustic properties of structural materials and structures is mainly based on measurements in reverberation rooms or chambers (Baruch *et al.* 2018, Zverev and Chernyh 2019), and impedance tubes (Zach *et al.* 2016). Based on such a way obtained experimental results, materials are then subjected to upgrade of their design leading to improvement of their acoustic properties, e.g. in case of brick blocks by utilization of bulk materials used in a role of filler (Fiala *et al.* 2018). Despite the fact that much effort has been devoted to the determination of acoustic properties of various types of materials by standardized methods, also applicability of other measuring techniques, such as measurements by using accelerometers, can be applied. Within the paper, acoustic experiments were conducted in terms of accelerometric measurements on two types of samples excited by acoustic waves in the frequency range of 1 – 10 kHz. Widely used materials in building practice with a significantly different structure were chosen, namely homogeneous steel prism and heterogeneous brick block with incorporated system of voids for enhancement of acoustic properties. The main purpose of the work was to compare experimentally determined data of such measurements that were prepared for further modeling.

2 EXPERIMENTAL

Within the experimental part, two different materials were chosen, namely homogeneous steel prism and heterogeneous brick block with incorporated system of voids. Dimensions of steel prism (Figure 1) were of (65.2 × 49.8 × 225.8) mm^3 and its mass was equal to 5618.7 g (density $\rho \approx 7664$ kg·m^{-3}). Brick block (Figure 2) was produced by company Heluz that is one of the leading brick producers in the Czech Republic. It consists of high porosity brick body and incorporated system of voids that is designed in order to enhance effective thermal and acoustic properties.

Figure 1. Steel prism with attached speaker and the screw for accelerometer positioning.

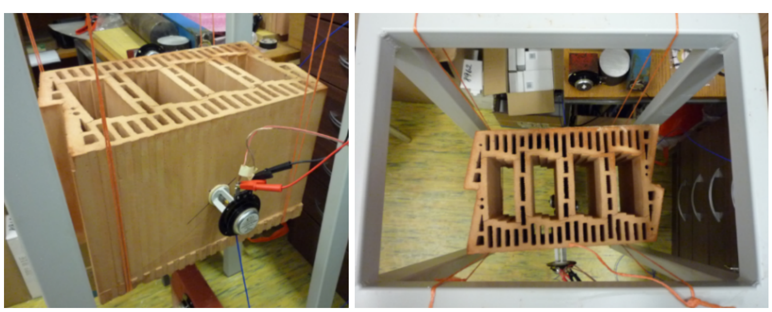

Figure 2. Arrangement of measurement – brick block hanged on cords.

Before the acoustic experiments, surface speaker was attached by two-component superglue X60 to a custom-made steel adaptor with screw thread for placement of accelerometer (Figure 3b). Opposite side of the adaptor was then attached to the central position of lateral side of the sample in the same way – steel bar surface, smoothened brick block surface (Figure 3c). A nut for placement of the second accelerometer was then attached to the central position of an opposite side of the sample (Figure 3d). Accelerometer placed to the adaptor was used for monitoring of the wave entering the sample (transmitter side), whereas the accelerometer placed to the nut on the opposite side for the wave propagated through the sample (receiver side). Consequently, samples were hung by cords suspended from redesigned steel supports. Further, to minimize acoustic noise from the surroundings, the samples were insulated using polyurethane boards.

Figure 3. a) Steel adaptor b) Adaptor with attached speaker c) Adaptor attached to the sample d) Accelerometer attached to the nut.

Input sine waves of particular frequencies within the frequency range 1 – 10 kHz were generated by arbitrary waveform generator GW Instek AFG-3051, amplified by Power Dynamics PDV240Z and converted to mechanical vibrations by surface speaker. In conjunction with a PC, an oscilloscope, GW Instek GDS-2104A, monitored input and output signals measured by piezoelectric accelerometers, PCB Piezotronics M352C66, supported by a datalogger, PCB Piezotronics 482C. One particular measurement involved determination of RMS voltages on accelerometers for a given frequency. Recorded signals from accelerometers were analyzed by means of oscilloscope built-in FFT functionality and stored to PC for further analysis focused on contribution of fundamental frequency signal and higher harmonics.

3 CALCULATIONS

First, voltage waveform of the signal measured by accelerometers was analyzed by oscilloscope and acceleration was calculated according to the formula in Eq. (1),

$$a = \frac{V}{c} \tag{1}$$

where a [m·s^{-2}] is the acceleration, V [mV] is the measured voltage and c [mV·s^{2}·m^{-1}] is the constant of a particular accelerometer.

With respect to velocity calculated by integration of acceleration and displacement that is calculated by integration of velocity, maximal displacement of a particular sine-wave of a given frequency D_{max} [m] can be expressed as shown in Eq. (2),

$$D_{\max} = \frac{a}{4\pi^2 f^2} \tag{2}$$

where a [m·s^{-2}] is the acceleration measured by accelerometers and f [Hz] is the exciting frequency. Due to observations of a significant voltage increase measured by accelerometers for some frequencies, it was proved by oscilloscope presence of composite sine waves that involve not just the fundamental frequency, but also higher harmonics. Therefore, further FFT analysis was performed and higher harmonics were taken into consideration by calculation of the total harmonic distortion THD_F [%] according to the formula given in Eq. (3),

$$THD_F = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \ldots V_n^2}}{V_1} \cdot 100 \tag{3}$$

where V_1 [V] is the fundamental voltage and V_2 [V], V_3 [V], V_4 [V] and V_n [V] are voltages corresponding to higher harmonic frequencies.

4 RESULTS AND DISCUSSION

In Figure 4, displacement and THD_F dependence on the frequency determined on steel prism in the range of 1 – 10 kHz are presented. Displacement varies between about 1 – 10 nm in those parts of the curve where THD_F is not significant. Two significant THD_F peaks for frequencies around 3.8 kHz ($THD_F \approx 15$ %) and 6 kHz ($THD_F \approx 50$ %) were observed in case of accelerometer placed on transmitter side. Such increase of THD_F led to a significant decrease of displacement on transmitter side. It is also evident contribution of 2nd harmonics around 7.8 kHz of fundamental frequencies between 3.4 – 4.4 kHz for the signal from accelerometer placed on transmitter side. Displacement on transmitter side was higher than on receiver side in the frequency range 7.3 – 10 kHz. In case of measurements on receiver side, there were not observed any significant THD_F peaks which corresponds with displacements on receiver side.
All

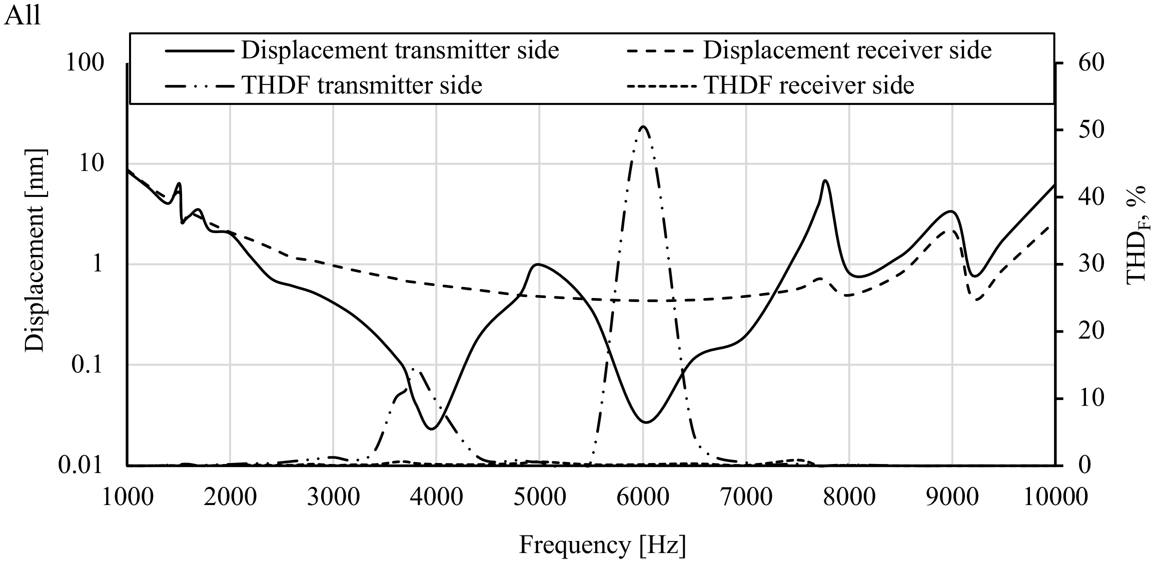

Figure 4. Displacement and total harmonic distortion – steel sample.

In Figure 5, displacement and THD_F dependence on the frequency for brick block measurements in the range of 1 – 10 kHz are presented. It is obvious that response on accelerometers is due to more complex structure significantly more sophisticated than that of the steel prism. There are obvious several THD_F peaks on both, transmitter and receiver curves which corresponds with decrease on displacement curves for given frequencies. In case of transmitter side accelerometer, THD_F peaks are within 1 – 3.5 kHz, whereas for receiver side two additional significant peaks are close to 6 kHz. The highest peak was observed for receiver side accelerometer was close to 90 % at 3.2 kHz.

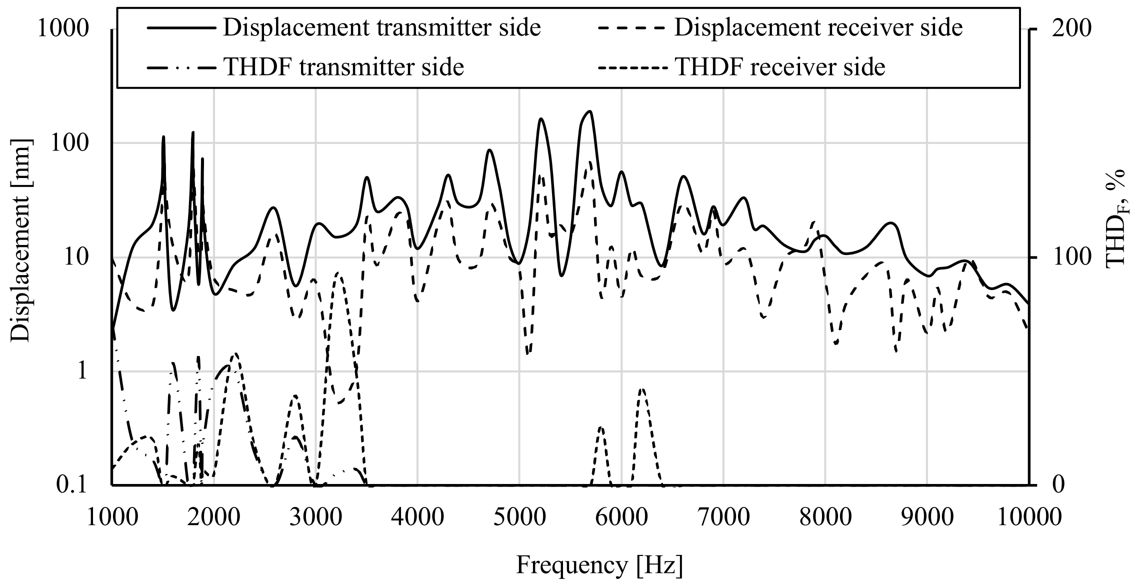

Figure 5. Displacement and total harmonic distortion – brick block sample.

5 CONCLUSIONS

In this paper, two materials with different structure were analyzed by accelerometers in terms of determination of acceleration, calculation of displacement and analysis of the measured signals. The first studied sample, steel prism is a typical homogeneous material which corresponds with simpler waveforms of the signals determined by accelerometers. Measurements on brick block with heterogeneous porous matric and system of incorporated voids provided much sophisticated waveforms. It was observed significant influence of higher harmonics at certain frequencies, which was proved by THD_F calculations and decrease of the displacement for given frequencies together with increase of displacement in frequencies corresponding to higher harmonics.

Obtained data are valuable for verification of acoustic (mechanical) models and successive modeling of acoustic behavior of building materials under acoustic load. It should be noted that further investigation is needed. The first objective lies in determination of shape ratio of the samples influence of the on results obtained by accelerometers. The second objective lies in accuracy analysis of such measurement method due to the fact that double integration of acceleration can significantly influence calculated displacements.

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