

Method of Testing of Sound Absorption Properties of Materials Intended for Ultrasonic Noise Protection

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Efficient ultrasonic noise reduction by using enclosures requires the knowledge of absorbing properties of materials in the frequency range above 4 kHz. However, standardized methods enable determination of absorption coefficients of materials in the frequency range up to 4 kHz. For this reason, it is proposed to carry out measurements of the sound absorption properties of materials in the free field by means of a tone-burst technique in the frequency range from 4 kHz to 40 kHz at angles of incidence varying from 0° to 60°. The absorption coefficient of a material is calculated from the reflection coefficient obtained by reflecting a tone-burst from both a perfectly reflecting panel and a combination of this panel and the sample of the tested material. The tests results show that mineral wool and polyurethane open-cell foam possess very good absorbing properties in this frequency range.

Keywords: ultrasonic noise, sound absorption coefficient, tone burst technique, sound absorbing material.

1. Introduction

A trend towards a growth of both the production efficiency and the quality level has contributed, among others, to development of technological applications of ultrasonic devices in which ultrasounds are generated for the purpose of either execution or acceleration or facilitation of assumed technological processes. These devices are characterized by relatively high power and their nominal frequencies in most cases are between 18 kHz and 40 kHz.

Ultrasonic cleaners are the most common devices. The ultrasonic cleaning technology applied for both miniature elements and large structures allows to obtain such a high surface cleanness degree that it is not possible to be achieved with other methods.

The ultrasonic cleaners are followed by ultrasonic drilling machines and ultrasonic welding devices. Ultrasonic drilling is particularly useful for making profile hollows or holes of any shape and high required accuracy regardless of the machined material. This method is used for machining of glass, quartz, natural and synthetic stones of any kind, porcelain, ceramics, titanium, as well as hardened steel and other metals difficult to machine. On the other hand, plastic and metal ultrasonic welding technologies are applied in

joining plastic elements (eliminating sizing technologies), in microwelding processes, and in joining fragile and/or hard-weldable materials.

Besides technological ultrasonic devices, there is also a large group of industrial machines and devices which also emit ultrasounds as an unintended accompanying additional factor. The sources of the ultrasounds are phenomena of aerodynamic nature (flow or outflow of compressed gases) or mechanical nature (high rotational speed of machine elements). The presence of ultrasonic components with significant sound pressure levels can be found in the noise in the surroundings of compressors, burners, valves, pneumatic tools and such high-speed machines as planers, millers, grinders, circular saws and certain textile machines. Most of the sound energy emitted by these machines to the environment is within high audible frequencies and low ultrasonic frequencies.

Working in the environment of the above-mentioned technological ultrasonic devices and machines creates hazards not only to the organ of hearing (SMAGOWSKA, MIKULSKI, 2008; SMAGOWSKA, 2011) but it can be also bothersome and even harmful due to extra-auditory effects of ultrasounds. It is estimated that about 25 000 employees in Poland are exposed to ultrasonic noise emitted by technological ultrasonic de-

vices and a similar number of employees are exposed to ultrasonic noise emitted by other machines and pieces of equipment.

In relation to the above, the permissible values of ultrasonic noise at work stations were defined in Poland (Minister of Labour and Social Policy, 2002). At the same time, the ultrasonic noise was defined as a noise in the spectrum in which components of high audible frequencies and low ultrasonic frequencies exist (from 10 kHz to 40 kHz) (AUGUSTYŃSKA, POŚNIAK, 2010).

Low frequency ultrasounds generated by the above-mentioned sources (technological ultrasonic devices, in particular) can penetrate the human body by means of contact (e.g. contact with an ultrasonic transducer or ultrasound-excited fluid). However, the sound energy originating from those sources is always transferred to the human body by means of air. The three basic methods or their combinations of lowering transferred ultrasonic energy are:

- isolation of the source (encapsulation),
- isolation of the receiver (hearing protectors),
- partitions between the source and the receiver.

Considering these primary ways of ultrasonic energy transfer to the human body, it is obvious that the most efficient way of limiting ultrasonic noise hazards are activities taken by device manufacturers consisting in encapsulation of ultrasound sources (in the case of technological ultrasonic devices) and limitation of noise source emissions (in the case of other machines). Due to the specificity of ultrasonic noise (short ultrasound waves) consisting in the occurrence of exposures mainly in the direct neighbourhood of noise sources, the most efficient protective means will be enclosures and acoustic screens which limit noise on its way of propagation. However, efficient noise reduction using the above-mentioned technical methods requires, among others, the knowledge of acoustic properties of materials (including the values of sound absorption coefficients for the materials) in the frequency range above 4 kHz.

2. Methods of determination of sound absorption coefficient

The impedance tube is typically used to measure the physical (normal) sound absorption coefficient. There are many types of impedance tubes. Some tubes are made of metal; other tubes, of a larger cross-sectional area, are made of air-tight and smooth concrete. The cross section of the tubes is usually circular and – less frequently – rectangular. The physical sound absorption coefficient can be determined by two standard methods: the method using the standing wave ratio (EN ISO 10534-1, 2001) or the transfer-function

method (EN ISO 10534-2, 2001). Moreover, the physical sound absorption coefficient for materials can be determined in the free field conditions using one of the following three methods (HIROSAWA *et al.*, 2009) consisting in:

- measuring acoustic impedance at a single point in the vicinity of the material,
- estimating impedance based on the transfer function between sound pressures measured at two points,
- estimating impedance based on the transfer function between sound velocities measured at two points.

However, for a dissipated (or dispersed) sound composed of waves propagating in all directions, the absorption coefficient has a certain mean value called the reverberant sound absorption coefficient α_s . This parameter characterizes a sound absorbing material and is determined on the basis of measurements made in laboratory conditions – in a reverberation room (EN ISO 354, 2003).

The above methods allow to determine the values of sound absorption coefficients for materials in a limited frequency range from 100 Hz to 5 kHz. The bibliography (SIKORA, 2011; TIJS, DRUYVESTYEN, 2012) or catalogues (*Acoustic absorption data* (n.d.)) sporadically present results of determining sound absorption coefficients in the frequency range up to 6300 Hz or 8000 Hz. In principle, there is no data available for a higher frequency range since the commonly applied reverberant standard methods can not be used in a high-frequency range due to strong sound absorption by air.

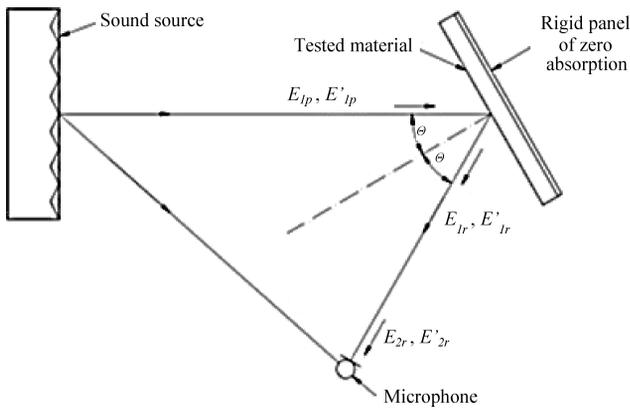
A solution to this problem could be the application of the reverberant standard method in a special miniaturized test chamber (DOBRUCKI *et al.*, 2010) or the use of the impulse method (the tone-burst technique).

3. Impulse method

The tone-burst technique consists in determination of sound absorption coefficient for a material using the impulse method as a function of a sound wave incidence angle in the free field conditions. Figure 1 presents the general principle of this method.

Assuming that:

- free field conditions exist,
- sound sources emit plane wave,
- the dimensions of the tested material are several times larger than the incident acoustic wave length,
- the sound absorption coefficient of the rigid panel is equal to zero,
- the energy losses between the tested material and the microphone do not depend on the tested material,



- E_{1p} – energy of an impulse incident at a rigid panel of zero absorption,
- E'_{1p} – energy of an impulse incident at a sample of the tested material placed on the panel,
- E_{1r} – energy of an impulse reflected from the panel,
- E'_{1r} – energy of an impulse reflected from the sample of the material,
- E_{2r} – energy of an impulse reflected from the panel reaching the microphone,
- E'_{2r} – energy of an impulse reflected from the sample of the material reaching the microphone,
- Θ – sound wave incidence angle.

Fig. 1. Principle of the sound absorption coefficient measurement using the impulse method.

the sound reflection coefficient can be expressed by the formula:

$$r = \frac{E'_{2r}}{E_{2r}} = \left(\frac{p'_{2r}}{p_{2r}} \right)^2 \quad (1)$$

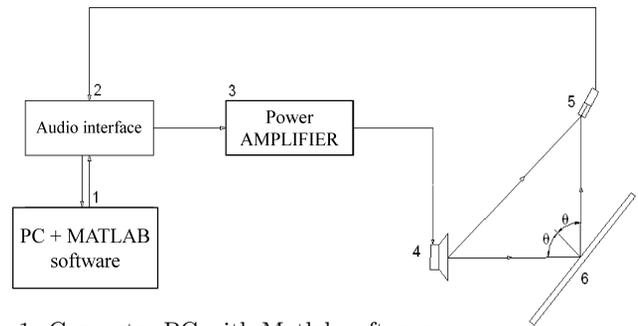
and the sound absorption coefficient can be determined from the relation:

$$\alpha = 1 - \left(\frac{p'_{2r}}{p_{2r}} \right)^2, \quad (2)$$

where p'_{2r} is the sound pressure of an impulse reflected from the tested material placed on the rigid panel, and p_{2r} is the sound pressure of an impulse reflected from the rigid panel.

Equation (2) implies that measurements of the sound pressure levels for both the impulse reflected from the tested material and the impulse reflected from the rigid panel should be carried out in order to determine the sound absorption coefficient.

A variable sound wave incidence angle with respect to the panel/tested material is obtained by a change of the panel position angle or by a possibility of controlling the position of the microphone and the sound impulse source. Figure 2 shows a diagram of a designed and constructed test stand for the measurement of the directional sound absorption coefficient using the impulse method in the frequency range from 4 kHz to 40 kHz.



1. Computer PC with Matlab software
 2. RME Fireface 400 audio interface
 3. B&K 2706 power amplifier
 4. Sound source
 5. 1/4" B&K 4135 measurement microphone
 6. Panel assumed as perfectly reflecting acoustic energy (the assumption is valid for the frequency range of 4 kHz – 40 kHz)
- Θ – sound wave incidence angle.

Fig. 2. Diagram of a test stand for the measurement of sound absorption coefficients for materials using the impulse method in the frequency range up to 40 kHz.

4. Test results

The experimental tests included sound absorption coefficient measurements in the frequency range from 4 kHz to 40 kHz for the following material samples:

- mineral wool with thickness of 60 mm, with a glass fibre mat (ROCKWOOL ROCKTON 60),
- mineral wool with thickness of 80 mm (ROCKWOOL ROCKTON 80),
- mineral wool with thickness of 100 mm (ROCKWOOL ROCKTON 100),
- polyurethane open-cell foam, with the corrugated front surface (APAMA G classic),
- furniture fibreboard with thickness of 4 mm over a distance of 1 cm from the rigid panel (on the frame around).

The measurements were performed in the above-mentioned frequency range in 200 Hz steps for the following sound wave incidence angles: 0°, 10°, 20°, 30°, 40°, 50°, and 60°. Examples of the measurement results are presented in Figs. 3, 4, and 5.

No significant effect of the sound wave incidence angle on the absorption coefficient value for mineral wool with thickness of 60 mm (Fig. 3) was found. The determined values of the coefficient in the examined frequency range and for the analysed angles of incidence are high, i.e. from 0.79 to 0.99, and the values exceeding 0.9 prevail. It can be noticed that local decreases of the sound absorption coefficient values generally occur for the same or neighbouring frequency bands for the given sound wave incidence angle.

However, an analysis of the results presented in Fig. 4 for mineral wool shows that there is no significant effect of the sample thickness on the sound

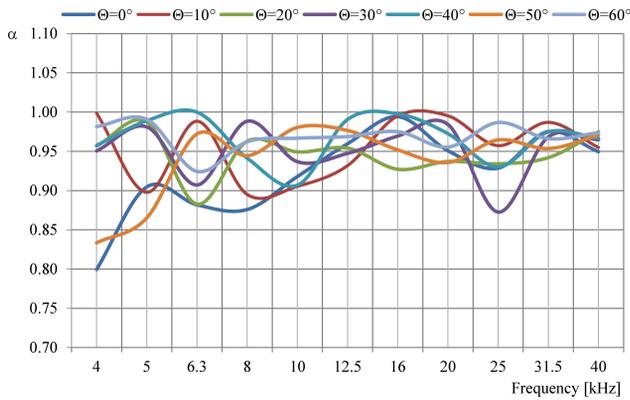


Fig. 3. Values of the directional sound absorption coefficients for mineral wool with thickness of 60 mm (ROCKWOOL ROCKTON 60) for the sound wave incidence angles of 0° , 10° , 20° , 30° , 40° , 50° and 60° .

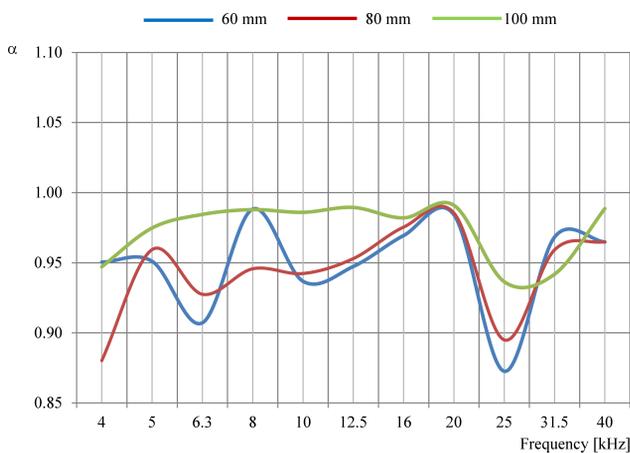


Fig. 4. Values of the directional sound absorption coefficient for mineral wool (ROCKWOOL ROCKTON) with thickness of 60 mm, 80 mm, 100 mm for the sound wave incidence angle of 30° .

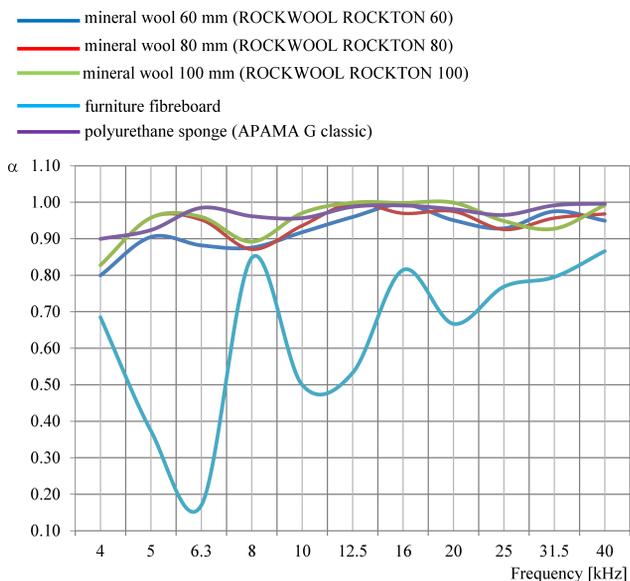


Fig. 5. Values of the directional sound absorption coefficients for tested materials for the sound wave incidence angle of 0° .

absorption coefficient values. Each of the tested mineral wool samples was characterized by high values of the sound absorption coefficient and for the incidence angle of 30° , they ranged from 0.88 to 0.99 and for frequencies above 10 kHz, the following relation can be observed: the larger thickness of mineral wool, the higher value of the sound absorption coefficient.

The latter of the above figures (Fig. 5) shows a comparison of the sound absorption coefficients of all tested samples for the sound wave incidence angle of 0° also known as the normal sound absorption coefficient. Except for the thin furniture panel which cannot be considered a good sound absorbing material (the sound absorption coefficient values for this sample vary from 0.37 to 0.86 and their distribution as a function of frequency reflects a resonance nature of this structure), the remaining materials possess very similar values of the sound absorption coefficients. The values are:

- from 0.79 to 0.99 for mineral wool with thickness of 60 mm (ROCKWOOL ROCKTON 60),
- from 0.82 to 1 for mineral wool with thickness of 80 mm (ROCKWOOL ROCKTON 80),
- from 0.83 to 1 for mineral wool with thickness of 100 mm (ROCKWOOL ROCKTON 100),
- from 0.9 to 1 for polyurethane open cell foam (APAMA G classic).

5. Conclusions

The knowledge of the sound absorbing material properties in the frequency range above 4 kHz enables proper selection of a design of collective equipment protecting from high-frequency noise (including ultrasonic noise) emitted by various machines and high speed devices as well as technological ultrasonic devices which are more and more commonly applied in modern manufacturing processes.

The developed impulse sound absorption coefficient measurement method for materials as a function of the sound wave incidence angle allows to determine the sound absorbing material properties in the frequency range from 4 kHz to 40 kHz.

The tests performed on mineral wool samples with different thickness (60 mm, 80 mm, and 100 mm) and polyurethane open-cell foam samples have shown:

- very good sound absorbing properties of mineral wool and polyurethane open-cell foam in the frequency range from 4 kHz to 40 kHz – in this frequency range, the sound absorption coefficient for the tested materials was close or equal to one,
- no significant effect of the mineral wool sample thickness on the values of the measured sound absorption coefficient, since thickness was larger than wave length of the incident signal,

- no significant relation between the values of the sound absorption coefficient for the tested materials and the sound wave incidence angle.

However, the results of the performed tests of the fibreboard in the rigid frame confirm not only a resonance nature of this structure which manifests itself in a large spread of the sound absorption coefficient values depending on the frequency and sound wave incidence angle, but the results also confirm worse sound absorbing properties of this sample in comparison with mineral wool and polyurethane open-cell foam.

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