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Method of Determining the Sound Absorbing Coefficient of Materials within the Frequency Range of 5 000–50 000 Hz in a Test Chamber of a Volume of about 2 m^3

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Sound absorption coefficient is a commonly used parameter to characterize the acoustic properties of sound absorbing materials. It is defined within the frequency range of 100–5 000 Hz. In the industrial conditions, many appliances radiating acoustic energy of the frequency range of above 5000 Hz are used and at the same time it is known that a noise within the frequency range of 5 000–50 000 Hz can have a harmful effect on people,hence there is a need to define the coefficient in this frequency range. The article presents a proposal for a method of measurement of the sound absorption coefficient of materials in the frequency range from 5 000 Hz to 50 000 Hz. This method is a modification of the reverberation method with the use of interrupted noise.

Keywords: ultrasonic noise, sound absorption coefficient of materials.

1. Introduction

Sound absorption coefficient is a commonly used parameter to characterize the acoustic properties of sound absorbing materials. Its variation called the sound absorption coefficient (EN ISO 354:2003) is defined by means of a measuring and computational method in a special reverberation chamber in conditions of diffuse field, with the use of interrupted noise or the impulse method (Blough *et al.*, 2007). Sizes of the studied sample of material are 10–12 m^2, and the volume of the test room is about 200 m^3.

Another method of defining the sound absorption coefficient and in particular its variation, the sound absorption coefficient (dependent on the angle of incidence of acoustic wave), is a measuring and computational method involving examination of small samples of material within the field of the standing wave in the so-called Kundt's tube. Both methods define this coefficient within the frequency range of about 5 000 Hz. In a range above this frequency the used methods cannot be applied. In the first case, diffuse field cannot be created in the examined room (which is an assumption of the applied method) because of a high level of attenuation of the sound in the air which is considerably higher than the measurable effect of multiple attenuation of the acoustic wave during its reflecting from the surface of the material sample being examined in a room of a volume of 200 m^3. In the second case, the measurements in a Kundt's tube are not possible for technical reasons. They are particularly limited by the diameter of the tube (the upper frequency of the measurements is limited by the condition that the wave must be twice as long as the diameter of the tube). (It has to be mentioned, that in some laboratories it has been attempted to define the coefficient of absorption in the examined frequency range, in the free field, i.e. in anechoic rooms, however, so far there have been no extensive reports on them (Pleban, 1990)). Hence the author suggests the use of a modification of the first method in a room (test chamber) of a reduced size (Dobrucki *et al.*, 2010).

2. The room for measurements of the reverberation time within the frequency range of 5 000–50 000 Hz – the test chamber

To define the sound absorption coefficient, the author suggests the research method applied in the diffuse field with the use of interrupted noise. The reason for adopting this method is the fact that the sound absorption coefficient of material should be determined in conditions similar to their use in practice. The use of sound-absorbing materials in the sources enclosures is expected.

The volume of a standard test room where the sound absorption coefficient is studied is about 200 m^3. The density of acoustic energy during propagation of the acoustic wave from the source decreases as a result of: an increase of the area of the surface wave front (for the point source – a sphere), losses of the acoustic energy during reflecting from the surfaces enclosing the room, and the attenuation of the acoustic energy during propagation in the air (ISO 9613-1:1993). All the three phenomena interact simultaneously and are taken into account in the method used up to this point. The influence of the second and third of these phenomena depends strongly on the frequency, however, within the frequency range investigated so far, 100–5 000 Hz, it is not too large for the conditions of the diffuse field not to be maintained (relatively small attenuation of the acoustic wave energy on the propagation path enables the recording of the acoustic signal above the acoustic background even after multiple reflections of the wave from the walls of the room – sufficiently long path on which the level of the sound pressure of the acoustic wave radiating from the source is higher than the acoustic background). The spectrum of the sound power level of the source is adjustable and can be relatively flat in the frequency range of 5 000–50 000 Hz (Mikulski, Radosz, 2009; 2010).

This is the basis for extraction of the energy losses during reflections from the influence of the three phenomena. It consists in setting the so-called decay curves of the sound pressure level after turning off the source and, from them, defining the reverberation time (from which the sound absorption coefficient is calculated).

In a standard test room (of about 200 m^3 volume), within the frequency range of above 5 000 Hz, sound attenuation by a material and the walls of the room and on the propagation path in the air is so high that the level of sound pressure decreases rapidly in the function of the distance. It makes it impossible to record the acoustic wave after multiple reflections and the impact of the reflection of a wave from the examined material cannot be extracted from the resultant impact of the three above mentioned phenomena. As a matter of fact, the distance covered by the acoustic wave whose density of acoustic energy is higher than the density of the acoustic field is so short that not only does it disable the occurrence of diffuse field but also makes it impossible to record even a few reflections of the wave from the walls of the room – which is a condition for measurement of the decay curve and, as a result, measurement of the reverberation time and the sound absorption coefficient. However, the author believes that this adverse state of matters can be changed. Since it is impossible to lengthen the above mentioned distance that depends, among others, on the attenuation of sound in the air, the number of reflections of the acoustic wave from the examined material sample on this distance should be increased. Then, the influence of the wave reflection on the attenuation in the air will be higher and it will be possible to create a quasi-homogeneous field (if not a diffuse field). Hence, it will be possible to measure the decay curves that will be most significantly influenced by the phenomenon of reflection of the wave from the examined material. The author suggests application of this solution by the use of two modifications of the applied standard method of defining the sound absorption coefficient in the diffuse field. The first, through a considerable reduction of the size of the test room and the second, through covering all the walls of the test room with the examined material (in the standard room 5% of the walls in the room are covered). This new room with a reduced size will still be called the test chamber.

The area of the inner surface of the test chamber has to be of the size of a standard sample of the examined material, i.e. about 10 m^2, it means that the minimal linear dimension (in meters) of the test chamber l (it was earlier assumed that it is a cube) is:

$$l \geq \sqrt{S_v/6} = 1.29 \text{ m}, \tag{1}$$

where S_v is the area of the inner surface of the chamber, in square meters.

Taking into account the standard thickness of the material sample, i.e. 0.05 m, the inner linear dimensions of the test chamber are assumed to be 1.4 m.

Figure 1 presents a section of the test chamber, its photograph, and a photograph of the research equipment.

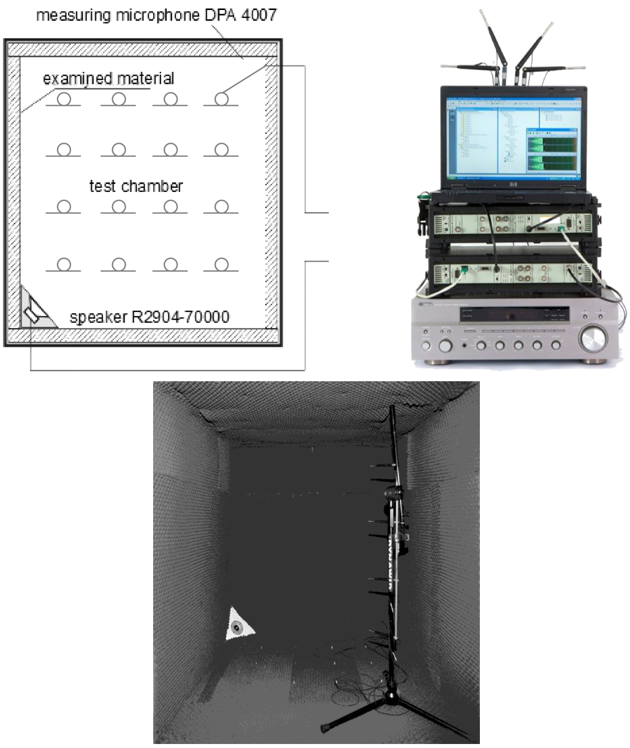

Fig. 1. Scheme (a scheme of the test chamber, the Pulse measuring system for the measurements in the examined frequency range (Mikulski, Radosz, 2009; 2010), a photograph of the test chamber).

3. Results of the measurements of the distribution of the sound pressure and the reverberation time in the test chamber

In the designed test chamber the research of the homogeneity of the created acoustic field in a steady state (of the level of the sound pressure on a spatial net, 64 points) and of the distribution of the reverberation time was carried out by means of the interrupted noise method. 64 measured points are in three-dimensional rectangular net $4 \times 4 \times 4$, i.e. four heights of 16 points Fig. 1. The distance from the net to the walls of the test chamber is 0.3 m). Both parameters were defined in 1/3 octave frequency bands, of mid-band frequencies of 5 000–50 000 Hz, in an empty chamber (wood) and with the examined materials: the polyurethane foam (Fig. 2) and mineral wool 50 mm.

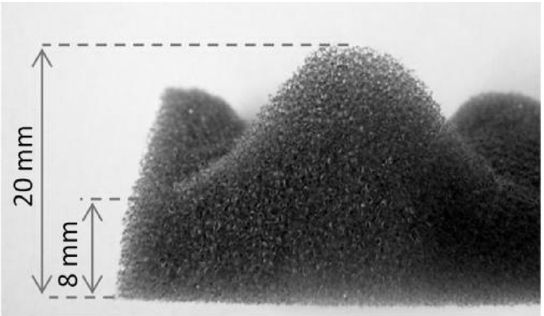

Fig. 2. Examined materials – the polyurethane foam.

The results of the tests are presented in:

- Fig. 3 – levels of the sound pressure,
- Fig. 4 – reverberation times.

The measurement results of the distribution of sound pressure level show that in the test chamber a homogeneous acoustic field occurs at a distance of more than about 0.5 m from the speaker, hence, every test should be carried out at a distance of more than 0.5 m from the speaker (compare Fig. 3 with 5 and 4 with 6). Figures 3 and 4 shows the results of measurements in 64 measurement points in the whole chamber (the closest measurement point is about 0.2 m from the speaker), and in Figs. 5 and 6 the results of measurements in 8 measurement points located in the middle of the test chamber are shown, the closest measurement point is about 0.6 m from the speaker.

It should also be noted that this condition is not critical, as in a standard test room creation of reverberant field is necessary because diffuse field is required due to a small area of the sample in relation to the size of the room. However, in the suggested test chamber, where all the walls are covered with the examined material, providing a diffuse field is not that significant.

The results of the measurements of the reverberation times do not vary significantly with respect to the value of this parameter in the test chamber. Thus, the choice of the point of measurement inside the chamber does not influence the measurement results of the reverberation time.

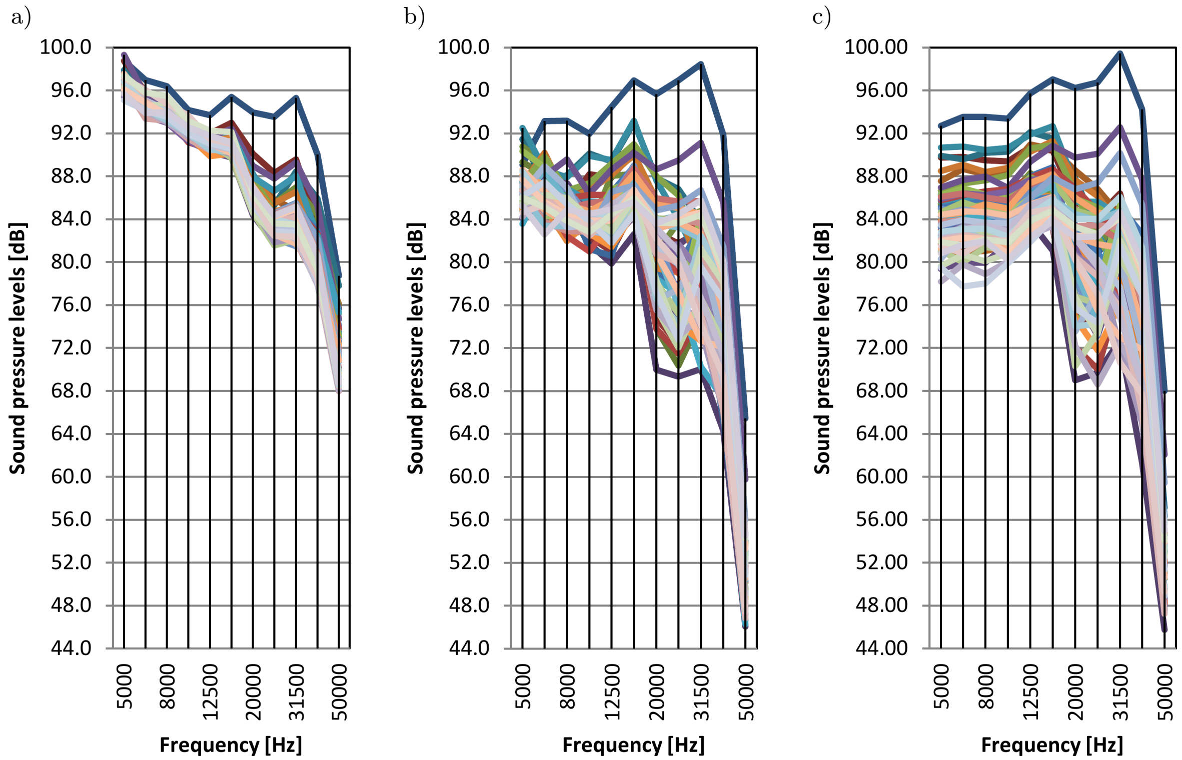

Fig. 3. Sound pressure levels in 1/3 octave frequency bands in the test chamber in a steady state: a) in an empty chamber, b) with polyurethane foam (Fig. 2), c) with mineral wool 50 mm, for 64 measurement point.

However, taking into account the maximum reduction in scatter of the measured values and limit of the number of measurement points, it is assumed that the optimal area in which the tests should be carried out is a sphere of the radius of 0.3 m in the centre of the test chamber (result of the level of the sound pressure inside the sphere presented in Figs. 5a–c – levels of the sound pressure, Figs. 6a–c – reverberation times).

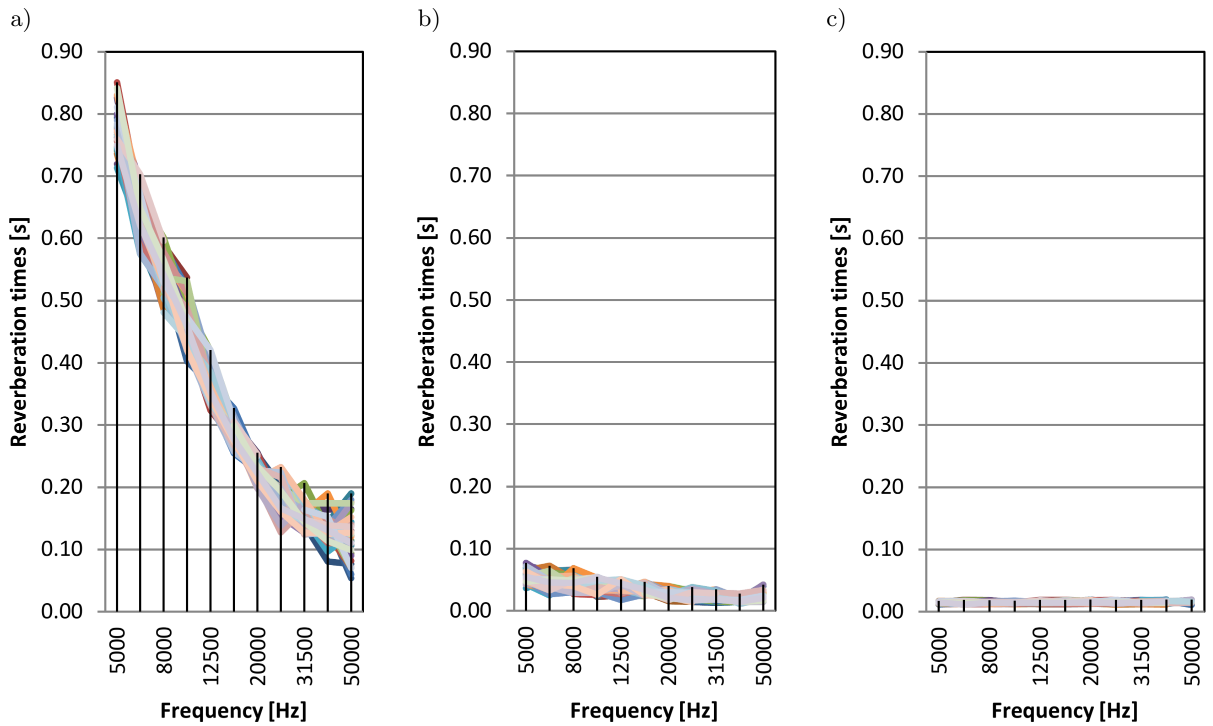

Fig. 4. Reverberation times in 1/3 octave frequency bands in the test chamber: a) in an empty chamber, b) with polyurethane foam, c) with mineral wool, for 64 measurement point.

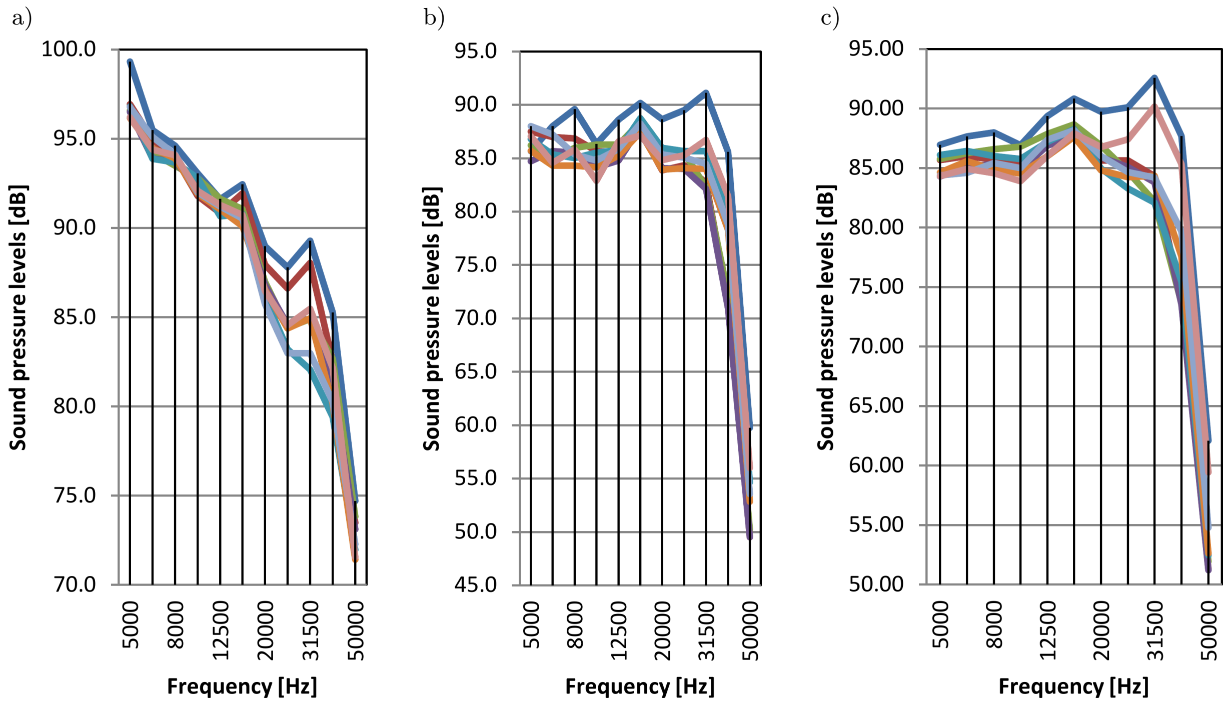

Fig. 5. Sound pressure levels in 1/3 octave frequency bands in the test chamber in a steady state: a) in an empty chamber, b) with polyurethane foam, c) with mineral wool, for 4 measurement point in the centre of the test chamber.

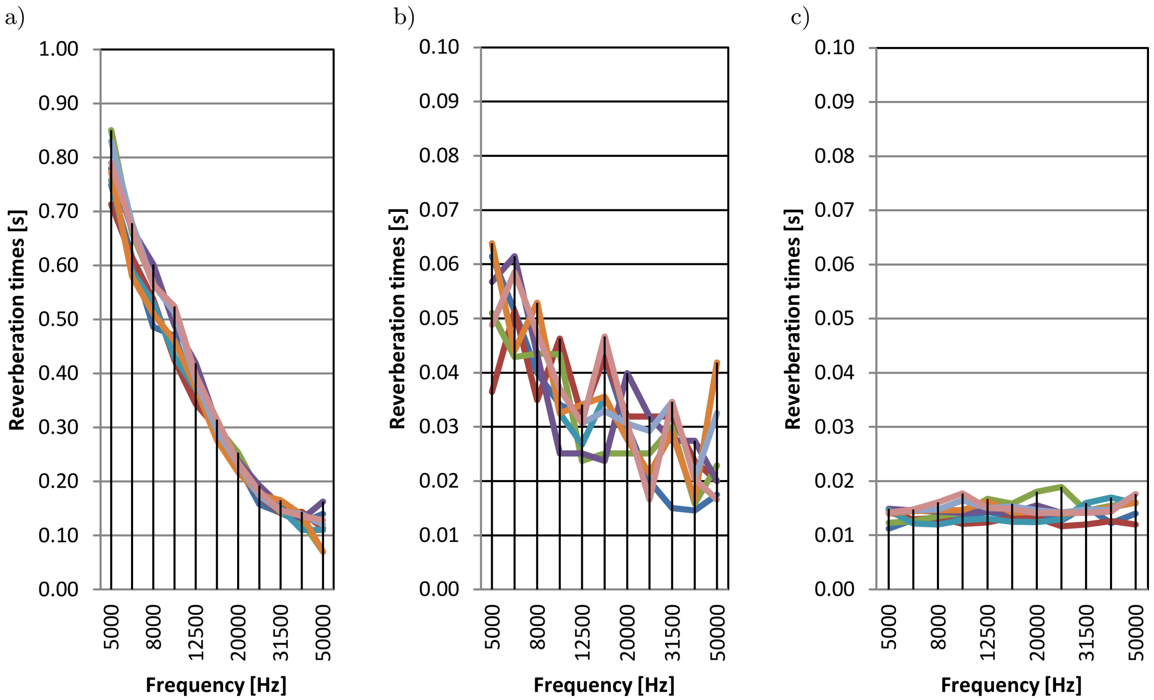

Fig. 6. Reverberation times in 1/3 octave frequency bands in the test chamber: a) in an empty chamber, b) with polyurethane foam, c) with mineral wool, for 4 measurement point in the centre of the test chamber.

4. Method of defining the sound absorption coefficient in the test chamber

While defining the sound absorption coefficient α in the test chamber from the results of the measurements of the reverberation time,we used the Knudsen formula which takes into account the high absorption properties of the material and the room $\alpha > 0.2$) and the sound attenuation in the air (that depends also on the humidity). Reverberation time (in seconds) in a room is defined by the use of the following formula:

$$T = \frac{0.161V}{-S_v \ln(1-\alpha_s) + 4mV}, \tag{2}$$

where T is the reverberation time in a room, in seconds; V is the volume of the test chamber, in cubic meters; S_v is the area of the inner surface of the chamber, in square meters; α_s is the average sound absorption coefficient in the room; m is the coefficient taking into account the attenuation of the sound in the air, dependent on the frequency and air humidity, in m^{-1} (for laboratory conditions the assumed values are in accordance with Table 1).

In the suggested method the sound absorption coefficient is defined after a transformation of Eq. (2), in frequency bands f, from the formula:

$$\alpha_f = 1 - e^{\frac{V}{S_v}\left[-\frac{0.161}{T_f} + 4 \cdot m_f\right]}, \tag{3}$$

where T_f is the reverberation time in the room, in 1/3 octave frequency bands of mid-band frequencies f (within the range of 5 000–50 000 Hz), in seconds; V is the volume of the chamber, in cubic meters; S_v is area of the inner surface of the chamber, in square meters; m_f is the coefficient taking into account sound attenuation in the air, in 1/3 octave frequency bands of mid-band frequencies f (within the range of 5 000–50 000 Hz), in m^{-1}.

Table 1. Coefficient m depends on the relative air humidity and frequency (for laboratory conditions).

Frequency [Hz]	Coefficient taking into account the attenuation of the sound in the air m [m^{-1}]
250	0.00009
500	0.00025
1000	0.0008
2000	0.0025
4000	0.007
8000	0.02

The coefficient m taking into account sound attenuation in the air depends on the frequency and humidity of the air and it is defined (at this stage of the research) by the use of the extrapolation method for the investigated frequency range of the coefficient given in Table 1. Power curve was used as the extrapolating function (the value of the correlation coefficient $R^2 = 0.9996$). The coefficient m_f (in m^{-1}) for laboratory conditions is defined from the formula (the values of this coefficient shall be specified by the author by means of the measurement method in later studies):

$$m_f = 2 \cdot 10^{-8} \cdot f^{1.57}. \tag{4}$$

The sound absorption coefficient of the room in 1/3 octave frequency bands α_f of mid-band frequencies within the range of 5 000–50 000 Hz, for laboratory conditions is defined from the formula:

$$\alpha_f = 1 - e^{\frac{V}{S_v}\left[-\frac{0.161}{T_f}+8\cdot 10^{-8}\cdot f^{1.57}\right]}, \tag{5}$$

where V is the volume of the test chamber, in cubic meters; S_v is the area of the inner surface of the test chamber (or with the examined material, the area of the material from the inner side of the chamber), in square meters; T_f is the reverberation time in the test chamber, in 1/3 octave frequency bands of mid-band frequencies f, in seconds; f – the mid-band frequency of 1/3 octave band, in Hz.

In the suggested method, the measurements of very short reverberation times are limited by the measuring equipment. Because this method is based on the measurement of sound fading in a room, it is necessary that the fading is slower than ringing out of the source. In the investigated measuring system, the established limiting value – the lower value of the reverberation time (defined in free field) – is equal to about 0.01 s, which corresponds in the investigated test chamber to a sound absorption coefficient $\alpha > 0.9$. Higher values of the sound absorption coefficient cannot be defined by means of this method; however, this limitation can be accepted taking into account the fact that in practical conditions there is no need to define the sound absorption coefficient above 0.9.

5. Measurement results of the reverberation time and sound absorption coefficient of a few selected materials

While calculating the sound absorption coefficient of materials within the frequency range of 5 000–50 000 Hz, formula (5) is used after measuring the reverberation time in the test chamber (presented in Fig. 1). To increase the accuracy of the measurements, the reverberation time measuring must be performed in 8 points of measurement on the measurement surface of a sphere of the radius of 0.3 m with its centre in the centre of the test room. Results should be averaged (arithmetically).

Verification of the method of determining the sound absorption coefficient was carried out in the frequency range in which one can conduct research in both the test chamber and the standard reverberation chamber. Figure 7 presents the result of the measurement of the sound absorption coefficient of a material made of polyurethane foam performed:

- in the reverberation chamber (Laboratory of the Building Research Institute in Warsaw, room volume of about 200 m^3) with a standard equipment for measuring the sound absorption coefficient of materials (method defined in the standard EN ISO 354:2003, derogation from this method: 2 500–10 000 Hz frequency range under consideration, the sound absorption coefficient is calculated from the formula (5),
- in the test chamber (Noise Laboratory in the Central Institute for Labour Protection – National Research Institute, volume of about 2 m^3) with the equipment set presented in Fig. 1, in the frequency band of 5 000–50 000 Hz.

It can be observed, that in the common frequency range, i.e. 2 000–4 000 Hz, the obtained results were similar, which proves the adequacy of the suggested method.

Figure 8 presents the sound absorption coefficient: of an empty chamber (wood), of a material made of polyurethane foam (Fig. 2), and mineral wool (50 mm).

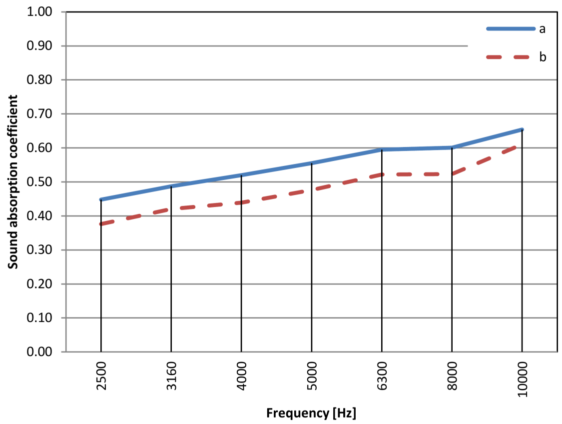

Fig. 7. Sound absorption coefficient of a material made of polyurethane foam in the frequency band 2 500–10 000 Hz: a – defined in a reverberation chamber in standard laboratory (volume 200 m^3), according to the method EN ISO 354:2003, b – defined by means of the suggested method in the test chamber.

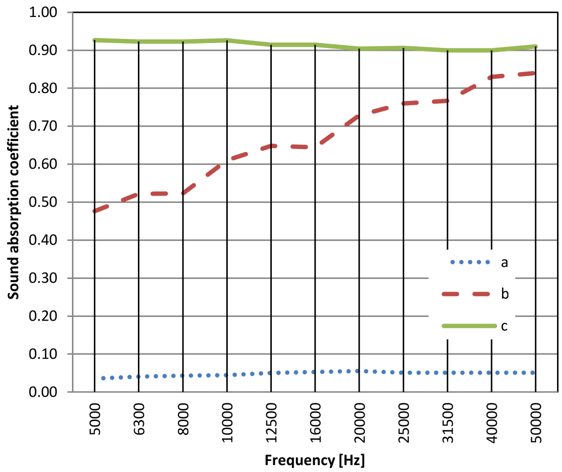

Fig. 8. Sound absorption coefficient of materials in 1/3 octave frequency bands of the test chamber: a – in an empty chamber (wood), b – with polyurethane foam, c – with mineral wool.

6. Result synthesis

The presented method makes it possible to define, by means of a measuring and computational method (with measurement of the reverberation time using the interrupted noise method), the sound absorption coefficient of a material in the frequency range of 5 000–50 000 Hz. The suggested method is defined as an assessment method, since further research has to be performed to enable estimation of its accuracy. It will be a difficult procedure, as in this frequency range properties of materials were not defined and investigated, so no data that could be used as reference is known to exist.

7. Conclusions

The elaborated method can be recognized as a research method which gives approximate results and in the future, after its validation, will be a method of defining acoustic properties of materials in the range of 5 000–50 000 Hz, with respect to their use as sound-absorbent materials for the surfaces of screens or insides of casings, etc.

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