Journal of MECHANICAL ENGINEERING – Strojnícky časopis,
VOL 68 (2018), NO 4, 55 - 64

METHODS OF TESTING OF SOUND INSULATION PROPERTIES OF BARRIERS INTENDED FOR HIGH FREQUENCY NOISE AND ULTRASONIC NOISE PROTECTION

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Abstract: Two test stands for determining sound insulation in the frequency range above 5 kHz were made. One consisted of two horizontally adjacent reverberation rooms and a special source of high frequency sounds and ultrasounds. The other test stand consisted of a miniaturized test chamber and a special source of ultrasounds. The paper presents results of the preliminary measurements of sound insulation properties of different barriers in the frequency range above 5 kHz.

KEYWORDS: high-frequency noise, ultrasonic noise, sound insulation, barriers

1 Introduction

Ultrasounds are widely used in industry, e.g. to detect surface defects of mechanical structures [1]. A special type of ultrasounds is ultrasonic noise. Ultrasonic noise is a specific kind of noise, i.e. noise whose spectrum contains components of frequencies ranging from 10 kHz to 40 kHz [2]. A trend towards a growth 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 execution or acceleration or facilitation of assumed technological processes. The devices are characterized by relatively high power. They are also the sources of high frequency noise and their nominal frequencies in most cases are between 18 kHz and 40 kHz.

Ultrasonic cleaners are the most common devices. They are sources of emission of ultrasounds whose sound pressure levels at operator workplaces reach the values of 110÷135 dB [3, 4]. The ultrasonic cleaners are followed by ultrasonic drilling machines and ultrasonic welding devices. They radiate into the air ultrasonic waves of sound pressure levels of up to 145 dB [5]. 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 the aerodynamic nature or the mechanical nature [4, 6].

Working in the environment of the abovementioned technological ultrasonic devices, machines and devices therefore creates hazards not only to the organ of hearing but it can be also bothersome and even harmful due to extra-auditory effects of ultrasounds. It is estimated that about 25,000 employees are exposed in Poland to ultrasonic noise emitted by technological ultrasonic devices 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 [7]. Low frequency ultrasounds generated by the above mentioned sources

DOI: 10.2478/scjme-2018-0047, Print ISSN 0039-2472, On-line ISSN 2450-5471 ©2018 SjF STU Bratislava

(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 neigh borhood of noise sources, the most efficient protective means will be enclosures and acoustic screens which limit noise on its way of propagation. 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 [8, 9, 10, 11, 12] and the knowledge of insulating properties of barriers in the frequency range above 5 kHz. Standardized methods [13, 14, 15, 16, 17] enable the determination of sound insulation of boards, barriers and construction elements in the frequency range up to 5 kHz. There is no data available for a higher frequency range since the commonly applied standard methods may not be used in a high frequency range due to strong sound absorption by air. This paper presents two methods of determining sound reduction index: the method using two adjacent reverberation rooms and the method using a miniaturized test chamber. Preliminary results are also given

2 Method using two adjacent reverberation rooms

2.1 Measuring method

In order to determine sound reduction index of barriers in the frequency range above 5 kHz a special method was developed. Tests are carried out in a suite of two horizontally adjacent reverberation chambers. The test elements are mounted in an opening in the partition between those chambers. The dimensions of the test opening are 0.7 x 0.7 m. Tests are carried out in accordance with the requirements of the standards EN ISO 10140-1 [13], EN ISO 10140-2 [14], EN ISO 10140-3 [15], EN ISO 10140-4 [16], EN ISO 10140-5 [17].

Determining sound insulation of a barrier consists in carrying out measurements of sound pressure levels in the source room and in the receiving room, followed by the calculation of the difference between the two values. The result is needed to calculate the specific sound reduction index R, in dB, from the following formula:

$$R = L_{p1} - L_{p2} + 10log\frac{S}{A} \tag{1}$$

where:

L_{p1} - averaged sound pressure level in the source room, in dB,
L_{p2} - averaged sound pressure level in the receiving room, in dB,
S - surface area of the tested partition sample, equal to the surface area of the test opening, in m^2,
A - sound absorption of the receiving room, in m^2.

Sound pressure measurements are carried out in the frequency range from 5 kHz to 12.5 kHz. Figure 1 shows a diagram of a designed and constructed test stand. The test stand consists of the following components: sound system in the source chamber, analysing and measurement chain, and test monitoring. The following instruments are used in the test stand:

- dual-channel analyser Nor 840 manufactured by NORSONIC with a built-in noise generator,
- power amplifier SOUND KRAK 200VA type,
- loudspeaker set with 20 broadband and high tone ScanSpeak Revelator R2904/700000 Tweeter loudspeakers, of a resonance frequency of 520 Hz, that can generate sounds in the frequency range of up to 40 kHz,
- two NORSONIC 1201 microphone preamplifiers,
- two automatic rotating booms (microphone grips) with PAN TILT controllers,
- CCTV cameras JBC-385/12 with Yamano Y1304M lens,
- monochromatic monitors BT-12 MC.

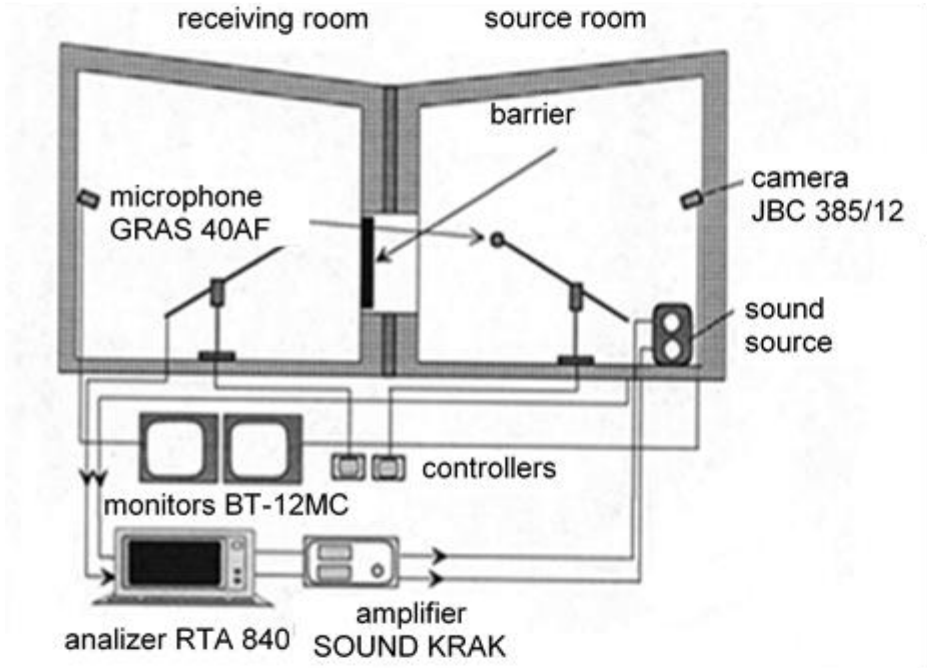

Fig. 1 Diagram of a test stand for the measurement of sound insulation of barriers

The source room is excited by broadband noise (white noise) generated by the noise generator of the NORSONIC Nor 840 analyser, via the power amplifier and the loudspeaker set. Acoustic signals from both rooms are simultaneously transmitted to the dual-channel analyser and averaged linearly for 12 s for each measurement point. Altogether, measurements of sound pressure are taken in 12 measurement points in the source room and in 12 measurement points in the receiving room.

2.1 Test results

Sound reduction index tests in the frequency range from 5 kHz to 12.5 kHz were carried out for the following barrier samples:

- sample No. 1.1 - a single, non-uniform rubber barrier 20 mm thick, consisting of the following layers glued to each other (using polyurethane adhesive): two exterior layers of standard 3 mm-thick PZ rubber with a core made of a textile-rubber waste of a 0-6 mm fraction,
- sample No.1.2 - a single sandwich panel 4.5 mm thick, consisting of the following layers glued to each other (using polyurethane adhesive): steel sheet 1 mm thick - EPDM rubber board 2.5 mm thick - steel sheet 1 mm thick,
- sample No. 1.3 - a single, uniform partition made of PVC 4 mm thick,
- sample No. 1.4 - a single sandwich panel 57 mm thick, consisting of the following layers glued to each other (using a double-sided adhesive tape): aluminium sheet 1 mm thick - sound absorbing air cell polyethylene board 55 mm thick,
- sample No. 1.5 - a single sandwich panel 58 mm thick, consisting of the following layers glued to each other (using a double-sided adhesive tape): aluminium sheet 1 mm thick - sound absorbing air cell polyethylene board 55 mm thick - aluminium sheet 1 mm thick.

Measurement results are presented in Table 1. Despite using high class loudspeakers, the achieved sound system level in bands above 10 kHz was not sufficient to ensure sound pressure level in the receiving chamber exceeding the noise generated by the instruments for these bands. In consequence, in all the cases, quite unexpected drops in sound reduction can be observed in the courses of insulation measurements in the last two bands (10 kHz and 12.5 kHz).

Table 1. Sound reduction indices *R* of the tested barriers, in dB

Number of the sample	Frequency [kHz]				
	5	6.3	8	10	12.5
1.1	51.8	53.1	52.3	50.0	41.7
1.2	49.1	51.0	51.7	45.5	39.9
1.3	45.9	46.0	47.5	47.0	46.1
1.4	51.2	56.5	57.3	51.0	45.2
1.5	53.9	56.0	58.5	57.0	53.2

3 Method using a miniaturized test chamber

3.1 Measuring method

Due to the fact that the method of determining sound reduction index of barriers elaborated and described in the previous chapter has a limited measurement frequency range, a second method was developed - a method using a miniaturized reverberation chamber.

In view of the above, a new parameter was put forward in order to characterise the soundproofing properties of barriers within the frequency range above 5 kHz, namely sound pressure insulation index for a barrier. Sound pressure insulation index for a barrier, D_U, in dB, is given by the formula (2):

$$D_U = L_1 - L_2 \tag{2}$$

where:

L_1 – sound pressure level in 1/3-octave bands with centre frequencies ranging from 5 to 25 kHz, as measured in a particular location where no barrier is installed in the measurement opening, in dB,

L_2 – sound pressure level in 1/3-octave bands with centre frequencies ranging from 5 to 25 kHz, as measured in a particular location where a barrier is installed in the measurement opening, in dB.

For thus defined sound pressure insulation index for a barrier, the key element of the test stand as set up for the determination thereof is a miniature test chamber in a form of a cube with a volume of 2.8 m3. It is made of multi-layered, compressed wood panels. In the top wall of the chamber, a measurement opening of 0.34 x 0.34 m is located, in which a barrier being tested is installed. Inside the chamber, a source of ultrasonic noise is installed, namely a SCAN SPEAK R2904/700000 tweeter. Other elements of the test stand include: a B&K 4190 microphone, a B&K 2669 preamplifier, a B&K Pulse system and a Yamaha RX-797 amplifier. The test stand was installed in an acoustic chamber in which conditions for free acoustic field above the sound-reflecting surface were met. The measurement microphone was installed in a central position in relation to the measurement opening, at a height of 0.25 m from the surface of the top wall of the miniature test chamber. Figure 2 shows a photograph of the miniaturized reverberation chamber with a measurement opening and clamping frame (in order tightly install the barriers being tested) in the top wall of the chamber.

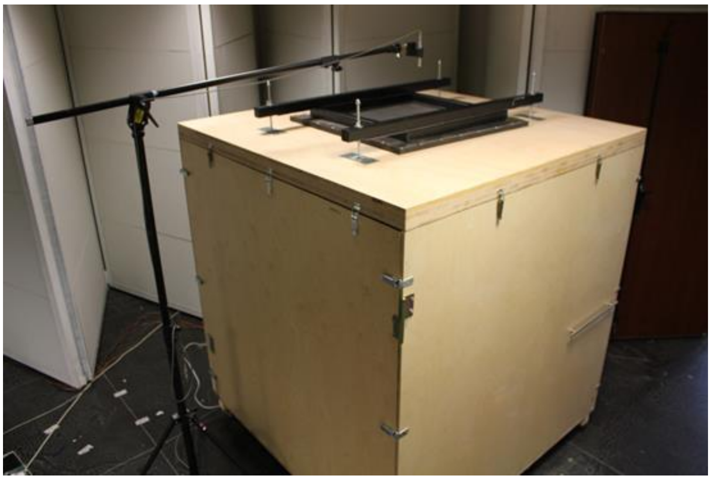

Fig. 2. A photograph of the miniaturized reverberation chamber

3.2 Test results

As part of the experimental tests, sound pressure insulation index values were determined in 1/3-octave bands with centre frequencies ranging from 5 to 25 kHz for 20 barriers: single-layered (8 barriers of various thicknesses made of MDF, PVC, PMMA, glass, and cement-bonded particle boards) and multi-layered ones (12 barriers made of layers of various thicknesses and combinations, including such materials as: steel sheet, sheet aluminium, rubber, granulated rubber, rubber crumbs, polyethylene, and MDF). The following barriers were tested:

- a single-layered, homogeneous barrier made of MDF fibreboard, 12 mm thick (sample No. 2.1),
- a single-layered, homogeneous barrier made of MDF fibreboard, 16 mm thick (sample No. 2.2),
- a single-layered, homogeneous barrier made of a PVC panel, 4 mm thick (sample No. 2.3),
- a single-layered, homogeneous barrier made of PMMA, 12 mm thick (sample No. 2.4),
- a single-layered barrier made of Cetris cement-bonded particleboard, 8 mm thick (sample No. 2.5),

- a single-layered, homogeneous barrier made of Cetris cement-bonded particleboard, 10 mm thick (sample No. 2.6),
- a single-layered, homogeneous barrier made of glass, 5 mm thick (sample No. 2.7),
- a single-layered, homogeneous barrier made of glass, 10 mm thick (sample No. 2.8),
- a multi-layered barrier 3.5 mm thick, consisting of steel sheet 1 mm thick, and a layer of solid rubber 2.5 mm thick (sample No. 2.9),
- a multi-layered barrier 4.5 mm thick, consisting of steel sheet 1 mm thick, a layer of solid rubber 2.5 mm thick, and steel sheet 1 mm thick (sample No. 2.10),
- a multi-layered barrier 6 mm thick, consisting of sheet aluminium 1 mm thick and a layer of coarsely granulated rubber bonded with a neoprene-type adhesive, 5 mm thick (sample No. 2.11),
- a multi-layered barrier 11 mm thick, consisting of sheet aluminium 1 mm thick and a layer of coarsely granulated rubber as bonded with a neoprene-type adhesive, 10 mm thick (sample No. 2.12),
- a multi-layered barrier 12 mm thick, consisting of steel sheet 1 mm thick, granulated rubber (rubber crumbs) 10 mm thick, and steel sheet 1 mm thick (sample No. 2.13),
- a multi-layered barrier 21 mm thick, consisting of sheet aluminium 1 mm thick, and a polyethylene closed cell foam sheet 20 mm thick (sample No. 2.14),
- a multi-layered barrier 22 mm thick, consisting of sheet aluminium 1 mm thick, polyethylene closed cell foam sheet 20 mm thick, and sheet aluminium 1 mm thick (sample No. 2.15),
- a multi-layered barrier 22 mm thick, consisting of rubber 3 mm thick, rubber with an additive, 16 mm thick, and rubber 3 mm thick (sample No. 2.16),
- a multi-layered barrier 22 mm thick, consisting of steel sheet 1 mm thick, granulated rubber (rubber crumbs) 20 mm thick, and steel sheet 1 mm thick (sample No. 2.17),
- a multi-layered barrier consisting of two MDF fibreboards, 12 mm and 16 mm thick (sample No. 2.18),
- a multi-layered barrier 51 mm thick, consisting of sheet aluminium 1 mm thick and a polyethylene closed cell foam sheet 50 mm thick (sample No. 2.19).
- a multi-layered barrier 52 mm thick, consisting of sheet aluminium 1 mm thick, polyethylene closed cell foam sheet 50 mm thick, and sheet aluminium 1 mm thick (sample No. 2.20).

The results for single-layered barriers are presented in Fig. 3 and in Table 2. Whereas test result for multi-layered barriers are presented in Table 3 and in Table 4.

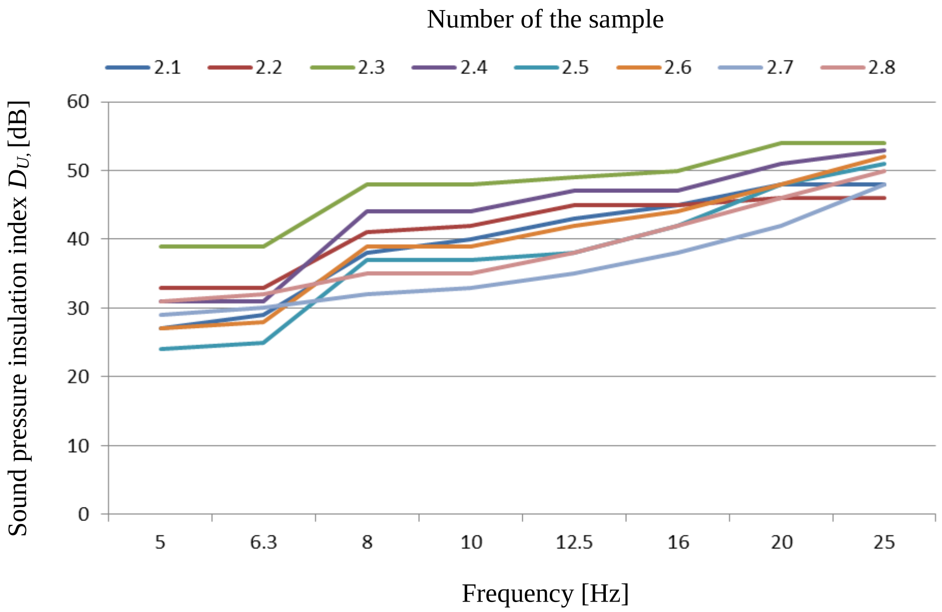

Fig. 3. Values of sound pressure insulation indices of the tested single-layered barriers

Table 2. Sound pressure insulation indices D_U of the tested single-layered barriers, in dB

Frequency [Hz]	Number of the sample							
	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8
5	27.0	33.0	39.0	31.0	24.0	27.0	29.0	31.0
6.3	29.0	33.0	39.0	31.0	25.0	28.0	30.0	32.0
8	38.0	41.0	48.0	44.0	37.0	39.0	32.0	35.0
10	40.0	42.0	48.0.0	44.0	37.0	39.0	33.0	35.0
12.5	43.0	45.0	49.0	47.0	38.0	42.0	35.0	38.0
16	45.0	45.0	50.0	47.0	42.0	44.0	38.0	42.0
20	48.0	46.0	54.0	51.0	48.0	48.0	42.0	46.0
25	48.0	46.0	54.0	53.0	51.0	52.0	48.0	50.0
Average value	39.8	41.4	47.6	43.5	37.8	39.9	35.9	38.6

Table 3. Sound pressure insulation indices D_U of the tested multi-layered barriers – samples 2.9, 2.10, 2.11, 2.12, 2.13 and 2.14, in dB

Frequency [Hz]	Number of the sample					
	2.9	2.10	2.11	2.12	2.13	2.14
5	39.0	41.0	44.0	36.0	47.0	47.0
6.3	40.0	45.0	40.0	37.0	49.0	48.0
8	48.0	54.0	44.0	40.0	50.0	52.0
10	49.0	54.0	41.0	45.0	54.0	58.0
12.5	49.0	55.0	43.0	46.0	55.0	59.0
16	50.0	56.0	44.0	48.0	59.0	60.0
20	54.0	56.0	49.0	54.0	59.0	61.0
25	54.0	57.0	50.0	55.0	60.0	62.0
Average value	47.9	52.3	44.1	45.1	54.1	55.9

Table 4. Sound pressure insulation indices D_U of the tested multi-layered barriers – samples 2.15, 2.16, 2.17, 2.18, 2.19 and 2.20, in dB

Frequency [Hz]	Number of the sample					
	2.15	2.16	2.17	2.18	2.19	2.20
5	48.0	44.0	48.0	42.0	47.0	48.0
6.3	49.0	47.0	50.0	43.0	51.0	52.0
8	56.0	51.0	56.0	47.0	60.0	62.0
10	58.0	52.0	57.0	48.0	60.0	62.0
12.5	60.0	52.0	58.0	54.0	61.0	63.0
16	60.0	55.0	62.0	58.0	61.0	64.0
20	62.0	58.0	67.0	58.0	62.0	65.0
25	63.0	58.0	68.0	59.0	63.0	65.0
Average value	56.9	52.1	58.3	51.1	57.5	60.1

Within the frequency range being measured, average sound pressure insulation index values for single-layered barriers being tested ranged from 39.5 to 47.6 dB. As regards single-layered barriers, the one with optimum insulation properties was a barrier made of a PVC panel 4 mm thick.

On the other hand, as regards the tested multi-layered barriers, average sound pressure insulation index values ranged from 44.1 to 60.1 dB. The latter value was determined for a barrier 52 mm thick, comprised of the following layers: sheet aluminium (1 mm), polyethylene closed cell foam sheet (50 mm), and sheet aluminium (1 mm)

CONCLUSION

The knowledge of sound insulation properties of barriers in the frequency range above 5 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.

Two methods were developed for the purpose of determining sound reduction index for barriers in the frequency range above 5 kHz. The first one enables measurements of specific airborne sound reduction index in laboratory conditions. Measurements are conducted in a suite of two reverberation chambers (source chamber and receiving chamber) linked by a measurement opening of 0.7 x 0.7 m. Determining specific airborne sound insulation index for a barrier consists in conducting measurements of sound pressure levels in both the source room and the receiving room, followed by the calculation of the difference between the two values as obtained.

The measurements of sound insulation carried out in a test suite comprising two reverberation chambers showed that the elaborated method can be applied in the frequency range between 5 kHz and 8 kHz. The results obtained in the tests demonstrate that:

- the tested samples of multi-layered barriers have very good soundproofing properties in the frequency range from 5 kHz to 8 kHz,
- the average sound reduction indices of the tested samples varied from 46.5 dB to 55.7 dB,

- the thickness of the barrier has influence on the sound insulation value - increasing the thickness of the barrier leads to a rise in the value of the sound reduction index,
- soundproofing properties of a single, uniform barrier are inferior to those of sandwich acoustic barriers of a similar thickness.
- The other method (using the miniaturized reverberation chamber) allows determination of sound pressure reduction index for a barrier. The reduction index in question is defined as a reduction in the sound pressure level in a particular location as a result of having installed a barrier in the measurement opening.

The developed method using the miniaturized reverberation chamber requires verification tests to be carried out. The tests carried out in accordance with this method have shown that:

- the method can be applied in the frequency range from 5 kHz to 31.5 kHz,
- the tested samples of single-layered and multi-layered barriers have very good soundproofing properties in the frequency range from 5 kHz to 25 kHz,
- the tested multi-layered barriers had better insulating properties than single-layered barriers,
- the average sound pressure insulation index values ranged from 39.5 to 47.6 dB for single-layered barriers and from 44.1 to 60.1 dB for multi-layered barriers,
- the best soundproofing properties were obtained for a barrier 52 mm thick, comprised of the following layers: sheet aluminium (1 mm), polyethylene closed cell foam sheet (50 mm), and sheet aluminium (1 mm),
- as regards the multi-layered barriers, a relationship between an increase in the value of sound pressure insulation index and an increase in the thickness of a barrier is observed.

Acknowledgements

This paper has been based on the results of a research task carried out within the scope of the second stage of the National Programme “Improvement of safety and working conditions” partly supported in 2011–2013 – within the scope of research and development — by the Ministry of Science and Higher Education/National Centre for Research and Development. The Central Institute for Labour Protection – National Research Institute is the Programme’s main co-ordinator

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