www.czasopisma.pan.pl www.journals.pan.pl
ARCHIVES OF ACOUSTICS
Arch. Acoust., **35**, 2, 157–164 (2010)
DOI: 10.2478/v10168-010-0014-4

Sound-Absorbing and Insulating Enclosures for Ultrasonic Range

Andrzej DOBRUCKI, Bronisław ŻÓŁTOGÓRSKI,
Piotr PRUCHNICKI, Romuald BOLEJKO

Wrocław University of Technology
Institute of Telecommunications, Teleinformatics and Acoustics
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland
e-mail: andrzej.dobrucki@pwr.wroc.pl

(*received May 4, 2010; accepted May 14, 2010*)

The physical phenomena occurring in sound-absorbing and insulating enclosures are subject of the present paper. These phenomena are: absorption in air and by the sound-absorbing material covering the walls and the coincidence effect. The absorption in the air can be neglected in small size enclosures for low ultrasonic frequencies (20–30 kHz). The coincidence plays a role in decrease of the sound insulation, however the main role play the leaks. The boards made of ceramic fibers have been chosen as the optimal sound-absorbing material. They are dense and have deeply porous structures. The enclosure for insulation of 20-kHz noise produced by a welding machine has been designed and manufactured, and reductions of 25 dB of peak and L_{eq} levels have been achieved.

Keywords: ultrasonic noise, sound absorbing and insulating enclosure, welder.

1. Introduction

The sound-absorbing and insulating enclosures are usually applied for reduction of the noise radiated by working machines in the industrial halls. The sound insulation is provided by either the heavy or layered walls. The sound absorption inside the enclosure is obtained by application of the sound absorbing material, e.g. mineral or glass wool for the covering of the walls. Some machines, e.g. welders, produce the noise in ultrasonic range 20–30 kHz (compare (Smagowska, Mikulski, 2008)). In this frequency range, the physical phenomena appear which should be taken into account in the process of designing of the enclosure. These phenomena are: sound absorption in the air, the coincidence between the acoustic waves in the air and bending waves in the walls. Also the properties of sound-absorbing materials are not known for ultrasonic frequencies.

The ultrasonic noise is hazardous for the health of the person directly operating the machine. According to Polish law (MLSP Regulation..., 2001), the following values of noise in ultrasonic frequency range should not be exceeded.

The SPL emitted by the welder at the distance of 1 m usually exceeds the values given in the Table 1. The L_{eq} for welder described in Sec. 5 was 108.5 dB, and $L_{\max} = 126.6$ dB. The operating frequency was 20 kHz, and the values of level were measured in the 1/3-octave band.

Table 1. Maximum permissible values of ultrasonic noise in the workplaces.

Center frequency of the 1/3-octave band [kHz]	Equivalent noise level related to eighthour work day [dB]	Maximum SPL [dB]
10; 12.5; 16	80	100
20	90	110
25	105	125
31.5; 40; 50; 63; 80; 100	110	130

2. Influence of sound absorption in air

The absorption of sound in the air is caused by a few factors: the viscosity, the thermal conduction and the relaxation processes explained by the theory of irreversible thermodynamics. The first two factors cause the increase of the absorption coefficient with a square of frequency, the third factor introduces deviations of this rule. The attenuation of the acoustic wave depends on the frequency, on the atmospheric pressure and on the relative humidity. The method of calculation of the sound attenuation (in dB/m) gives the standard (ISO 9613-1, 1993). The results of calculations are presented in Table 2.

Table 2. Attenuation of sound in the air for atmospheric pressure 101325 Pa, relative humidity 50% and temperature 20°C.

Frequency [kHz]	2	4	8	10	20	30	40
Attenuation [dB/m]	0.010	0.030	0.105	0.159	0.525	0.936	1.318

The attenuation of the sound within an enclosure can be taken into account by modification of the absorption coefficient of the material covering the walls of enclosure. Let us consider the enclosure of volume V and surface of walls S. The walls are covered with the material of the absorption coefficient α. The mean free path of sound is expressed with the equation (Knudsen, 1932):

$$l_{\text{mean}} = \frac{4V}{S}. \tag{1}$$

The intensity level of sound running the mean free path and reflecting from the wall is reduced by the value:

$$\Delta L = 10 \log \frac{1}{1-\alpha} + l_{\text{mean}} \cdot Att, \tag{2}$$

where Att is attenuation per unit distance. This reduction of the intensity is equivalent to the modified absorption coefficient α':

$$\Delta L = 10 \log \frac{1}{1-\alpha'}. \tag{3}$$

Comparison of Eqs. (2) and (3) yields:

$$\alpha' = 1 - \frac{1-\alpha}{10^{0.1 \cdot Att \cdot l_{\text{mean}}}}. \tag{4}$$

For example, for the cubic enclosure of $V = 1$ m^3, $S = 6$ m^2, the mean free path $l_{\text{mean}} = 0.67$ m. If the walls are covered with the material of $\alpha = 0.8$, then Eq. (4) yields for frequency 20 kHz ($Att = 0.525$ dB/m) a modified coefficient $\alpha' = 0.816$ and for frequency 40 kHz ($Att = 1.318$ dB/m) $\alpha' = 0.836$. Then, for small enclosures and frequencies up to 40 kHz, the attenuation is a weakly significant factor for decrease of sound level.

3. Influence of coincidence

For the homogeneous construction of the walls of the enclosure and for low frequencies, the so-called mass law is valid. It can be expressed as (Sadowski, 1976):

$$R = 20 \cdot \log(f \cdot m) - 47.5 \text{ dB}, \tag{5}$$

where R – sound reduction index [dB], f – frequency [Hz], m – mass per unit area [kg/m^2], $m = \rho \cdot h$, ρ – density of wall material [kg/m^3], h – thickness of the wall [m]. The sound reduction index increases with frequency 6 dB/oct. In the enclosure walls the bending waves appear but for low frequencies, the sound radiation by these waves is inefficient. However, above the frequency, for which the speed of bending waves becomes the value of the speed of sound in air, the efficiency of sound radiation by bending waves increases and it causes significant decrease of acoustic insulation of the enclosure. The coincidence frequency is expressed by the following equation:

$$f_c = \frac{c^2}{2\pi} \sqrt{\frac{\rho h}{B}}, \tag{6}$$

where $c = 344$ m/s – speed of sound in air, B – bending stiffness (E – Young's modulus, ν – Poisson's ratio):

$$B = \frac{E h^2}{12(1-\nu^2)}. \tag{7}$$

The walls of designed enclosure were made of PMMA (Polymethyl metacrylate) and the door was made of polycarbonate, both of thickness $h = 10^{-2}$ m. The data of these materials are:

Table 3. Data of the material used for the enclosure.

Material	Young modulus [MPa]	Poisson's ratio	Density [kg/m^3]
PMMA	2500	0.3	1185
Polycarbonate	2400	0.3	1200

The calculated coincidence frequencies are:

- For PMMA $f_c = 4280$ Hz.
- For polycarbonate $f_c = 4400$ Hz.

These frequencies are located far below the considered ultrasonic range. Then, the coincidence effect influences significantly the sound reduction index. The value of R for frequency $f = 20$ kHz, according to formula (5), is for PMMA and polycarbonate almost the same and it is equal to 60 dB. The SPL inside the enclosure (with walls covered with sound-absorbing material) was equal to ca. 117 dB and outside the enclosure, in the immediate vicinity, it was equal to 84 dB. The sound reduction index by the walls can be assessed as the difference $117 - 84 = 33$ dB. Then, the influence of both the coincidence and the leak of the enclosure can be evaluated and equals 27 dB.

4. Influence of sound-absorbing material

The indoor walls of the enclosure should be covered with sound-absorbing material in order to reduce increasing of the sound level inside the enclosure. The data of absorption coefficient for sound-absorbing materials in ultrasonic frequency range are usually not provided by the manufacturers. The choice of suitable sound-absorbing material was preceded by measurements of the absorption coefficient. Because of a high frequency range, the measurement has been done in small reverberation chamber of volume 27 litres. The measured samples had the dimensions 20×14 cm^2. The chamber with the sample inside is presented in Fig. 1. The measurement procedure was performed according to the standard ISO 354:2003 (2003). The scale of the chamber is 1:20 in comparison with the standard. The measured samples had the dimensions 20×14 cm^2, what is equivalent to 11 m^2 in the scale 1:1. For the samples of high thicknesses, the side area influences significantly the results. The suitable corrections have been introduced to the results. The sound was produced by the electric sparks. The PSD of the source measured in 1/3-octave band is presented in Fig. 2.

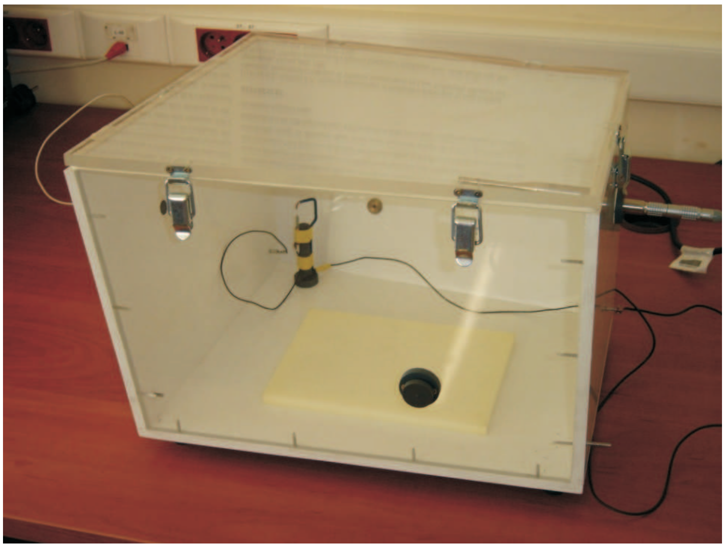

Fig. 1. The chamber for measuring of the sound absorption coefficient in ultrasonic frequency range.

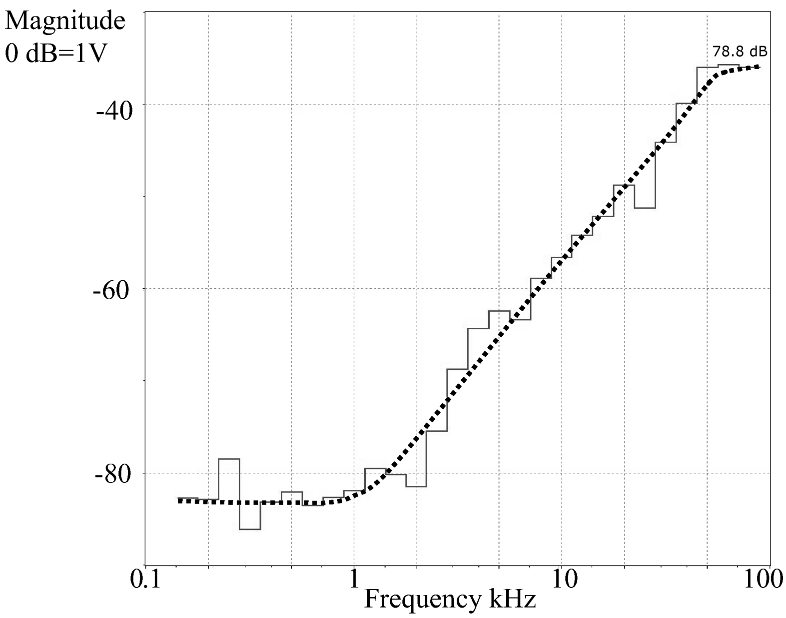

Fig. 2. Power spectrum of the sound source used in measurements.

The results of measurements are presented in Fig 3. Four materials were measured: two samples of the board made of ceramic fibers (of thickness 1 cm and 6 cm), Ecophone^{TM} of thickness 4 cm and Polyurethane foam of thickness 1 cm. Results of measurement are presented in Fig. 3.

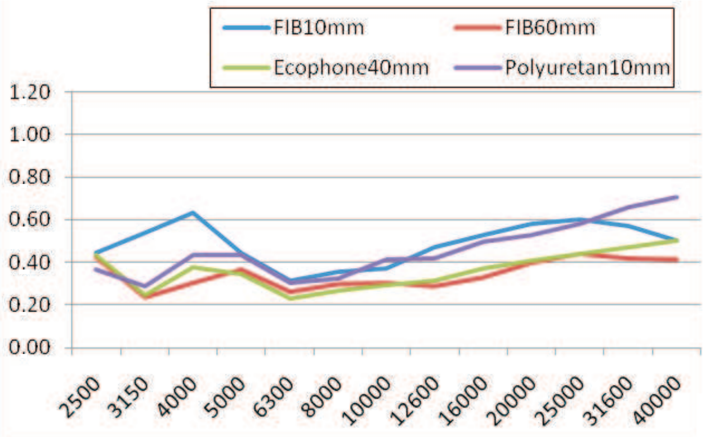

Fig. 3. Measured values of the sound absorption coefficient for various materials.

The best results for frequency $f = 20$ kHz are been obtained for the 10-mm thick board of ceramic fiber and this material has been chosen for the designed enclosure. It provided the highest reduction of SPL inside the enclosure – from 121 dB (with walls without any absorbing material) to 117 dB in 1/3-octave of center frequency 20 kHz.

5. Case study

The motivation for the work was a contract with a factory manufacturing the food processors for home use, made of plastics. The ultrasonic welder produced at the workplace in the distance of ca. 1 m from the welding sonotrode, the SPL levels $L_{eq} = 108.5$ dB, and $L_{\max} = 126$ dB for working frequency 20 kHz. In the measuring point is the head of the person operating the welder; then the sound reduction was necessary. Daily duration of the exposure is equal to 450 minutes. Because the exposure should be related to 480 minutes, the measured level should be corrected by -0.28 dB. The results of measurements and calculated values of exceed indicator K are presented in the Table 4. Many technical problems have been solved during realization of the task. The operating person places the welded elements at the welding area. Their hand should be removed from this area, then he or she must initiate the process of welding by pressing two buttons placed at the operating field. It is necessary to use two hands for this operation. If the enclosure is used, the door should be opened for placing the elements at the welding area and it should be close during the welding operation. During eight hours, this operation repeats ca. 3500 times. Duration of single welding operation is 1.4 s. Then, the door should be opened and closed automatically. It was achieved by the design of a control device for these operations. This device controls the actuator. The enclosure was made of the PMMA and the door – of

Table 4. Noise data of the welding system before reconstruction.

$L_{eq,8\text{h}}$; K							
Frequency [kHz]	10k	12.5k	16k	20k	25k	31.5k	40k
Measurement 1	80.1	78.3	77.5	108.9	89.3	83.5	101.7
Measurement 2	79.8	73.1	77.8	108.7	89.8	83.2	100.6
Mean value	80.0	75.7	77.7	108.8	89.6	83.4	101.2
Mean value corrected to 8h	79.7	75.4	77.4	108.5	89.3	83.1	100.9
Permissible value	80.0	80.0	80.0	90.0	105.0	110.0	110.0
Exceed indicator K	0.93	0.35	0.55	**71.12**	0.03	0.00	0.12
$L_{\max,8\text{h}}$; K							
Measurement 1	97.2	86.5	94.5	126.6	106.9	98.6	118.5
Measurement 2	98.2	85.0	93.6	125.5	105.8	103.9	120.7
Maximum of (1, 2)	98.2	86.5	94.5	126.6	106.9	103.9	120.7
Permissible value	100.0	100.0	100.0	110.0	125.0	130.0	130.0
Exceed indicator K	0.81	0.21	0.53	**6.76**	0.12	0.05	0.34

the polycarbonate, because of its higher hardness. The walls are covered with the boards of ceramic fibers. Because of a complicated mechanical structure, the serious problem was leaking. Careful seal significantly improved the sound reduction outdoors of the enclosure. The welder with the enclosure is presented in Fig. 4.

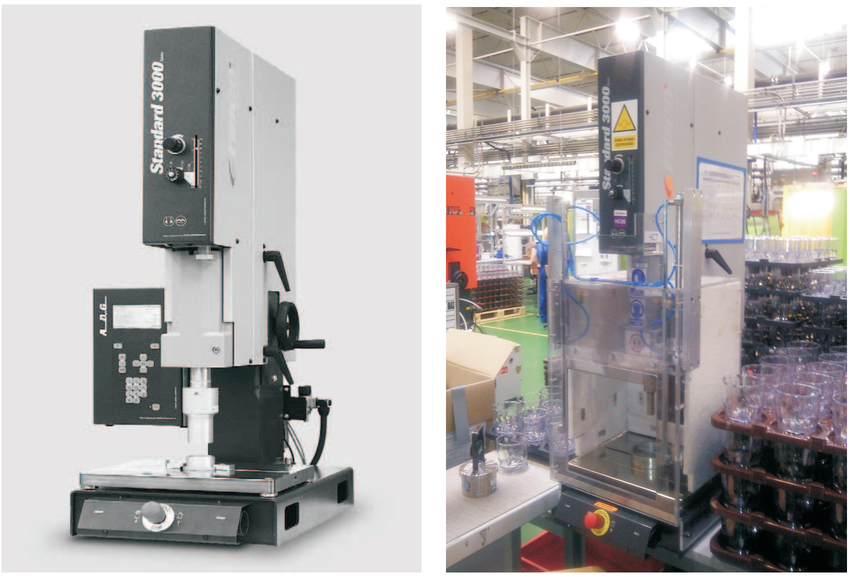

Fig. 4. The welding machine before and after rebuilding, i.e. with the sound-absorbing and insulating enclosure.

The following values of SPL have been obtained at the reference point outside of the enclosure: $L_{eq} = 83.8$ dB, and $L_{\max} = 97.6$ dB in 1/3-octave band at 20 kHz. Then the insertion loss of the enclosure is not less than 25 dB for basic operating frequency.

6. Conclusions

Some aspects of design of the sound-absorbing and insulating enclosures, working in ultrasonic frequency range, have been presented in the paper. Such enclosures are applied at workplaces with ultrasonic devices, e.g. welders. The SPLs produced by these devices exceed the permitted values. During the design process, the physical phenomena which do not appear in acoustic range should be taken into account. The sound absorption coefficients in ultrasonic frequency range should be determined because the manufacturers of these materials do not provide their data for ultrasonic frequencies. The optimal materials are different than those in acoustic range.

Other important phenomenon is the coincidence effect which decreases significantly the sound reduction index of the walls. It would be useful to continue the research on the properties of sound-absorbing materials as well as on construction of walls for ultrasonic frequency. The sound absorption in air, at least for lower ultrasonic frequencies, seems to be a less significant factor. The leak of noise energy through even small technological openings is a real, serious problem to overcome and it significantly influences the final magnitude of the enclosure sound reduction index.

References

1. ISO 9613-1:1993, Acoustics – Attenuation of sound during propagation outdoors.
2. ISO 354:2003, Acoustics – Measurement of sound absorption in a reverberation room
3. Knudsen V.O. (1932), *Architectural Acoustics*, New York.
4. MLSP Regulation of January 2, 2001 on the maximum permissible concentration and intensity of harmful factors in the work environment, Official Gazette, 4, 36, 2001.
5. Sadowski J. (1976), *Architectural Acoustics* [in Polish], PWN Warszawa–Poznań.
6. Smagowska B., Mikulski W. (2008), *Noise at ultrasonic drill systems – evaluation of health risk* [in Polish], Bezpieczeństwo Pracy (Work Safeness), **10**, 18–22.