Research of noise reduction in frequencies and sound reduction index of construction with variable noise isolation

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Abstract

Intense sound levels produced by engineering equipment have become an acute issue. As most of engineering equipment require air supply, exhaust and good ventilation, it is not possible to control the noise by covering them with tight hoods. Louvre with blades covered with acoustic materials and gaps that enable free circulation of air are used to this end. Three louvre configurations were tested in the semi-anechoic chamber: louvre blades not covered with any sound absorbing material, louvre with blades covered with 20 mm-thick polystyrene foam slabs on both sides and louvre with blades covered with 15 mm-thick glass wool slab ISOTEC KVL. According to the test results, louvre with blades covered with glass wool slab ISOTEC KVL demonstrated the best noise attenuation characteristics. The reduction of equivalent sound level subject to blade inclination angle was from 10.8 to 12.5 dB. Noise level reduction by louvre with blades covered with polystyrene foam slabs was weaker: the reduction of equivalent sound level was from 5.4 to 8.4 dB. Louvre with blades not covered with any acoustic material demonstrated the worst noise attenuation result from 1.9 to 3.9 dB.

1 Introduction

In Lithuania, like in other countries, noise mitigation efforts are made. However, noise control measures and techniques still cause numerous debates (Cerezci *et al.* 2015, Zavadskas *et al.* 2009). In urban areas the average annual increase in noise levels is about 1-3 dB (Gražulevičienė *et al*. 2009). Many industries pay great attention to noise mitigation products to handle the increasing noise in the environment. Vehicle manufacturers, aircraft designers, engine manufacturers, HVAC equipment producers design and develop noise control systems for their products (Shoureshi 2004). The main noise control techniques are architectural planning, noise attenuation at the source, noise absorption and insulation (Valikonienė 2001). The best and simplest noise control technique is modification of noise generating equipment (Bies and Hansen 2009). Other engineering noise control alternatives are acoustic screens, jackets, casings. Portable acoustic casings are made of light acoustic materials. Vinyl or glass fibre composites are used as acoustic materials. The acoustic structure may be also made of different layers, where one layer is made of 100 % cotton and other layers are made of cotton and other materials combined at the proportion of 35-65 %. (Hanna andKandil 1991). Shields are used in industrial shops to protect work spaces, on the plant territory to reduce the transmission of noise from the source to offices and neighbouring residential districts. The selection of noise control structure involves consideration of its height, sound wave reflection and absorption capacity, a sufficiently high reduced noise area behind the screen (Venckus *et al.* 2012).

The level of noise generated by engineering equipment depends on the noise source, distance from a source to a receiver and the natural working environment (Ouis 2002). The noise generated by an industrial machine depends on the share of mechanical and electrical energy transformed into acoustic energy. Acoustic fields are aggregated from many noise sources: the noise transmitted through the air, the air transmitted through the structure, diffraction of sound waves, reflection of sound waves from the floor, the walls, the ceiling, equipment surfaces, sound absorption, etc. (Randall 2003).

Noise has a direct effect on human health, the quality of the living and resting environment (Sanford 2007). Noise has an adverse effect on both human health and the entire human body (Baltrėnas and Puzinas 2009). Continuous noise can cause sleep disorders, reduce the working capacity (Stanfeld *et al.* 2000), deteriorate mental and physical health (Babisch 2005), cause stress.

Prolonged exposure to 85 dB or higher noise level can cause the hearing loss (Atmaca 2005). The aforementioned outcomes of prolonged exposure to noise causes negative changes to human reactions, including changes in homeostasis. In the long run there are negative effects on the heartbeat, muscular tonus, electric conductivity in brain; emotional stress is accompanied by hypertension and ischemic heart disease (Tamošiūnas *et al.* 2005).

In many cases noise control structures have to ensure air supply, exhaust and good ventilation of engineering equipment. In such cases hoods and booths cannot be used as they are tight and prevent the free movement of air. Noise is easily transmitted in open spaces, therefore noise control requires structures that permit free movement of air and at the same time absorb the noise (Asdrubaliand Buratti 2005). To this end, acoustic louvre are used. Acoustic louvres are used to mitigate the noise from air ventilation systems, engineering equipment, noise from buildings (Oldham et al. 2004). Louvres have different configuration, form of blades, and inclination angle that enable to control pressure loss, whereas noise absorbing material infilled in the blades provides sound insulation. Such louvres permit air circulation and protect the equipment from varying weather conditions. Sound insulation offered by acoustic louvres is not very high, especially in low frequencies (Viveiros *et al.* 2002). According to Ken Marriott, the highest effectiveness of acoustic louvres is reached in high frequency band of 1 000-3 000 Hz.

Commercial louvres are of standard configuration; usually the blade width, inclination and air gap differ. Acoustic louvre must not only have good acoustic properties but must also be aerodynamically effective (Bibby, Hodgson 2013). Traditional louvre consists of a metal frame, the bottom part of which is filled with sound absorbing material. Most often the bottom part is perforated to protect the material from bad air conditions. Acoustic louvre may be mounted both outside and inside the building to reduce the noise generated by ventilators, generators, transformers, HVAC equipment.

The aim of the paper is to determine the effectiveness of noise insulation of the louvre prototype with blades covered with different noise absorbing materials on both sides tested in semi-anechoic chamber.

2 Methodology

Experimental research with acoustic louvre was done in the semi-anechoic chamber designed by the Environment Control Institute of Vilnius Gediminas Technical University. This chamber is used for measuring sound absorption, reverberation and insulation properties of different materials and structures made of them (verification method defined by EN ISO 140 – 3).

Semi-anechoic chamber is made of two rooms separated by a double wall, and an adjacent room where the measuring instruments are located. One room is conventionally called the sound source and the other room is called the sound receiver.

Each semi-anechoic chamber room is sound-proofed by rockwool sheets. Such configuration enables to reduce the indirect noise transmission between the chamber rooms and to minimize the background noise sounds in the rooms. A 1 m^2 size opening is made in the wall between the semi-anechoic chamber rooms, where the test specimen of 1.0 x 1.0 m dimensions is fixed tightly. The specimen is made of 7 metal blades of equal dimensions: the length is 1 m, and the width is 0.3 m. The tested materials are fixed onto the blades: 20 mm-thick polystyrene foam and 15 mm-thick glass wool slab ISOTEC KVL single-faced with black glass veil (figure 1).

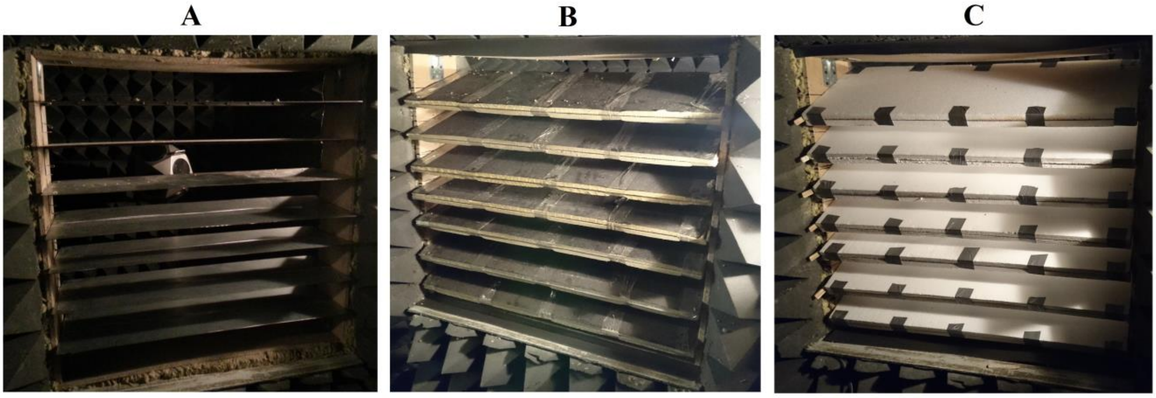

Fig. 1. 1a- construction with blades not covered with noise absorbing material; 1b – construction with blades covered glass wool slab ISOTEC KVL; 1c – construction with blade covered with polystyrene foam slab.

One-third octave frequency band filter is used for sound level measurement. The measurement time in every separate microphone spot and in each one-third octave frequency band is at least 60 s. The measurement is done by changing the louvre blade inclination angle at 15 degrees increment in the range from 0 to 45 degrees. The top of the blades is turned towards and away from the noise source (Figure 2). The following parameters are measured:

- The average sound pressure level in the source room.
- The average sound pressure level in the receiver room.
- The average reverberation time in the receiver room.
- The reduction of sound pressure level in the entire frequency band.
- The equivalent sound pressure level difference.

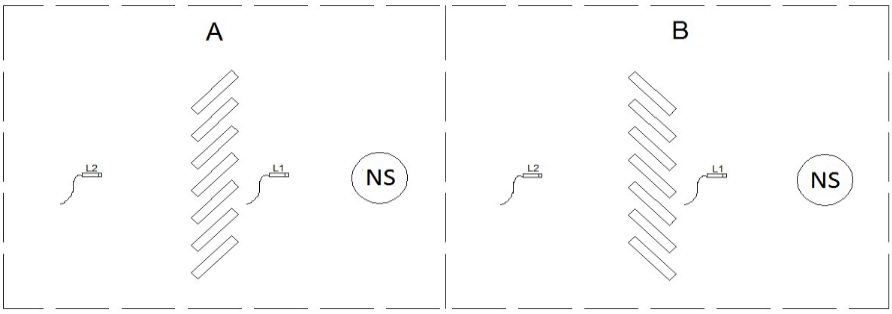

Fig 2. 1a – blades turned away from the noise source; B1b – blades turned toward the noise source; NS – noise source; L1 – average noise level in the receiver room; L2 – average noise level in the source room;

Sound insulation R_w is calculated from the obtained parameters by means of computer software BZ 7210 Qualifier. Sound insulation index R_w is computed as the 10 logarithm to base 10 of the ratio of the sound power L_1 radiated to the testing partition and the sound power L_2 transmitted through the specimen. Sound insulation R_w is expressed in decibels and computed from the equation (after Rasmussen and Rindel 2010):

$$R_w = L_1 - L_2 + 10\lg (S/A); \tag{1}$$

where: L_1 is the average noise level in the source room, dB; L_2 is the average noise level in the receiver room, dB; S is the area of the test specimen equal to the opening area of the empty semi-anechoic chamber in square metres;

$$A = \frac{1.163 \cdot V}{T} \tag{2}$$

where: V – volume of the incoming sound chamber, m^3; T – measured reverberation time, s.

Prior to conducting the test in the semi-anechoic chamber the level of background noise is measured. The value of the equivalent background noise in the in semi-anechoic chamber was 18.7 dBA.

Prior to conducting the noise attenuation test the level of noise in semi-anechoic chamber is tested for compliance with background noise requirements: the background noise level in all microphone locations in all selected frequency bands must be at least 10 dB lower than the source noise level, the air temperature during the measurement shall be not below 15 ^{0}C and not above 30 ºC.

The following Bruel&Kjaer measuring instruments were used for the test: microphone calibrator 4294, real time sound spectrum analyser Bruel&Kjaer mediator 2260D, microphone Bruel&Kjaer 4189, microphone Bruel&Kjaer 4189, Omnipower omnidirectional noise source 4292 (UA1690), amplifier (30ºW) 2716, software Qualifier BZ 7210, Testo 452.

3 Results

The louvre was made of seven 300 mm-wide and 1 000 mm-long metal blades mounted into a wooden frame of 1 m^2 with 120 mm air gaps between the blades. The blades are mounted so that they can be turned at different inclination angles in both directions. The louvre is placed in the semi-anechoic chamber. Prior to the test the noise level in the receiver room is measured and later used as a reference noise level L1. The effectiveness of the louvre is tested by using the white noise of the same level. The noise attenuation effectiveness of the designed structure was tested by measuring the reduction in noise level. The difference between the noise level in the receiver room with and without the louvre is presented in the diagrams below.

Firstly the louvre with metal blades not covered with noise absorbing material was tested. The effectiveness of the louvre was measured by inclining the blades towards the noise source at 0º, 15º, 30º, 45º angles. The results are presented in Figure 3.

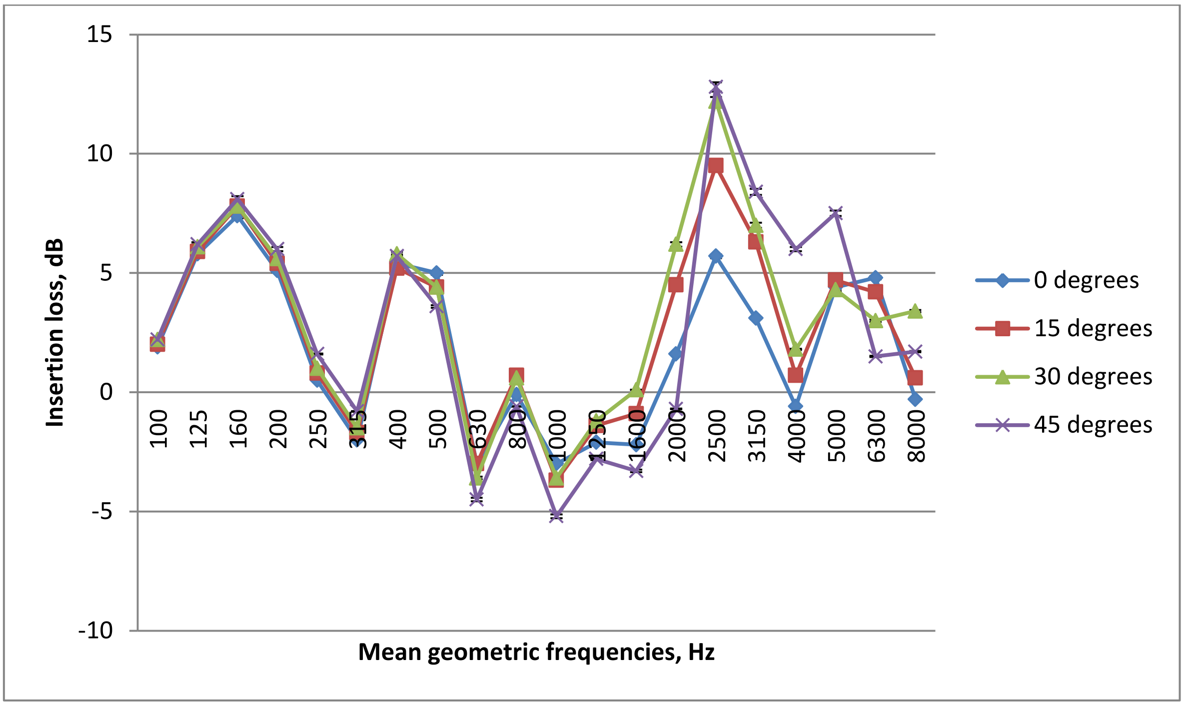

Fig. 3. Reduction of sound pressure level in the frequency range by the louvre with blades not covered with noise absorbing material and inclined towards the noise source

The effectiveness of the structure in the frequency range from 100 to 1000 Hz did not change at different inclination angles of the blades. In frequency band from 100 to 250 Hz the structure with blades not covered with sound absorbing materials reduced the sound level down to 7 dB. The sound level also reduced at frequencies 400, 500 and 800 Hz. At frequencies 315, 630 and from 1 000 Hz to 2000 Hz the sound level increased due to wave interference. From frequency 2 000 Hz the sound level started to change subject to the blade inclination angle as there was no wave interference. The blade length became longer than the sound wave length. In frequency band from 2 000 to 8 000 Hz the best noise attenuation was observed with blades inclined at 45º angle, and the worst noise attenuation was at 0º, as expected. The biggest noise level reduction was at 2 500 Hz frequency. When the blades were inclined at 45º angle, the noise level was reduced 13 dB, at 30º angle the reduction was 12 dB, and at 15º angle the reduction was 9 dB.

The effectiveness of the structure was also tested with the blades inclined away from the noise source at 0º, 15º, 30º, 45º angles. The results are presented in Figure 4.

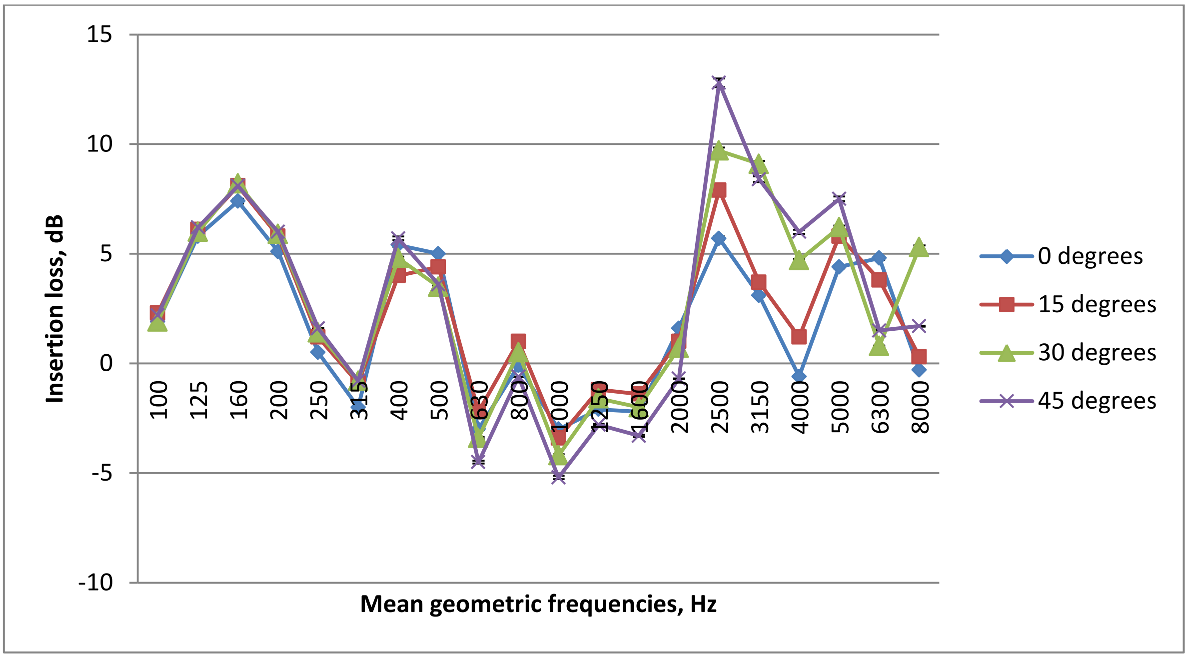

Fig. 4. Reduction of sound pressure level in the frequency range by the louvre with blades not covered with noise absorbing material and inclined away from the noise source

The reduction of noise at different inclination angles becomes different only from 630 Hz frequency. At low frequencies 100-315 Hz the noise level reduces to 8 dB. At 315 to 1600 Hz frequencies the noise level increases due to wave interferention. From 2000 Hz due tu wave diffraction, when wave becomes longer than the blade, insertion loss increases. The graph shows that the biggest reduction in the noise level is observed when the blades are inclined at 45° angle and noise frequency is 2500 Hz .When the blades were inclined at 45° angle, the noise level was reduced 13 dB, at 30° angle the reduction was 9 dB, at 15° angle the reduction was 7 dB and at 0^0 angle the reduction was 6dB. At 4 000 Hz frequency the biggest difference between the inclination angles is observed. In this frequency band the biggest noise level reduction is obtained when the blades are inclined at 45° angle and the reduction decreases with the decrease of the inclination angle.

The values of calculated sound insulation R_w in Db and equivalent noise level reduction L_{Aeq} in dB(A) are presented in Table 1.

Table 1. Sound insulation R_w and equivalent noise level reduction L_{Aeq} with louvre blades not covered by acoustic materials

Louvre blade inclination angle	Frequency, Hz							Sound insulation R_w	Equivalent noise level reduction L_{Aeq}, dB(A)
	63	125	250	500	1000	2000	4000		
0°	9.5	23.2	5.7	3.8	5.5	10.7	2.6	7	1,9
15° towards the source	9.8	23.0	5.6	3.5	5.3	11.6	5.4	8	3,1
30° towards the source	10.0	23.2	5.5	3.6	5.5	14.4	8.3	8	3,5
45° towards the source	10.2	23.5	5.4	3.5	5.4	16.1	8.3	8	3,9
15° away from the source	9.8	23.0	5.9	3.6	5.3	9.5	4.3	7	2,8
30° away from the source	9.9	23.2	5.8	3.3	4.9	9.5	8.0	7	3,2
45° away from the source	10.1	23.5	5.7	2.9	3.8	9.5	6.9	6	3,5

According to the figures in table the equivalent noise level reduction was higher with blades turned towards the noise source. The obtained results show that better reduction of equivalent noise level is achieved with louvre blades inclined at bigger angle. When louvre blades were inclined away from the noise source, the equivalent noise level reduction was lower but results also show, that better reduction of equivalent noise level is achieved with louvre blades inclined at bigger angle.

To increase the effectiveness of the structure and noise absorption properties, the blades of the tested structure were covered with acoustic materials on both sides. Light and thin materials were chosen. As structures of this type can be used both for the interior and facades of the buildings, two different acoustic materials were tested. The first material is 20 mm-thick polystyrene foam featuring closed air-filled pores that make the foam impervious to moisture and contaminants and thus suitable for both interior and exterior applications. The second tested material is firm and solid 15 mm-thick glass wool slab ISOTEC KVL single faced with black glass veil. This material has good noise absorption properties; however is not suitable for exterior applications.

When covered with polystyrene foam the blade thickness was 50 mm and the gaps between the blades were 800 mm. Noise level reduction achieved by the structure with blades inclined towards the noise source at 0°, 15º, 30º, 45º angles are presented in Figure 5.

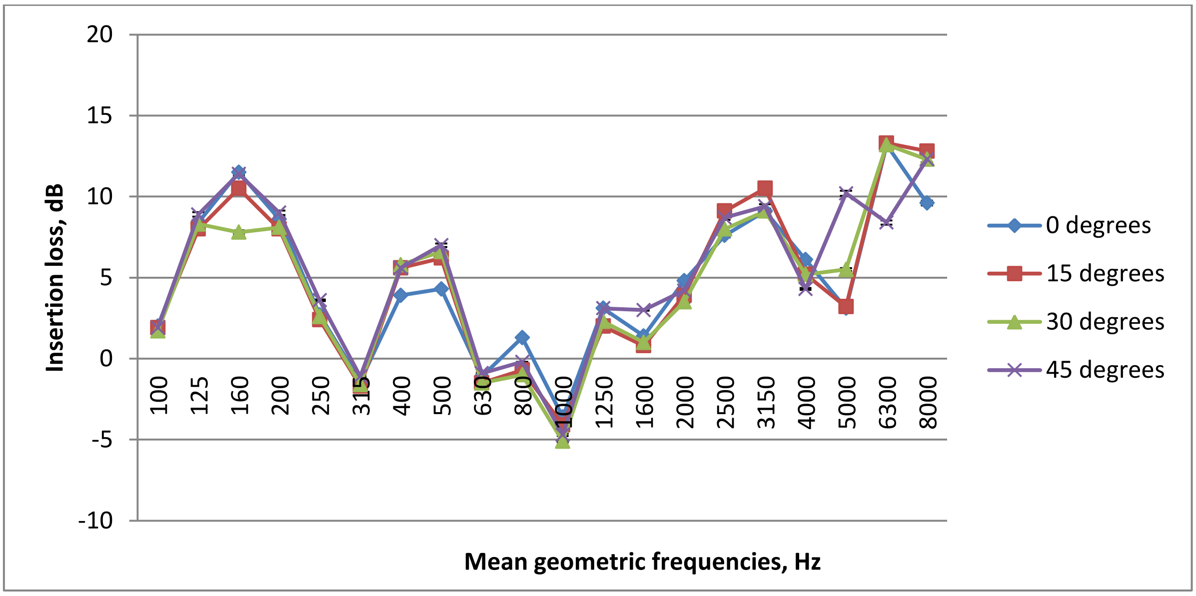

Fig. 5. Noise level reduction in the entire frequency band by the structure with blades covered with polystyrene foam and inclined towards the noise source

In the low frequency band from 100 to 315 Hz the equivalent noise level reduction does not depend on the blade inclination angle. At 160 Hz frequency a sharp noise level reduction of 11 dB was observed. At 315 Hz frequency the noise level increased and at 400 and 500 Hz frequencies the noise level reduced. As a result of wave diffraction the noise level reduces in higher frequency band starting from 1 250 Hz, however, it should be noted that no significant differences were observed in relation to blade inclination angles. The most significant differences in noise level reduction were observed at 5 000 Hz frequency, where the biggest reduction was obtained with louvre blades inclined at 45° angle, and the least noise level reduction was observed with blades inclined at 0° and 15° angles. The biggest noise level reduction of 14 dB was recorded at 6 300 Hz frequency.

Noise level reduction was also measured with louvre blades inclined away from the noise source at 0°, 15°, 30°, 45° angles. The results are presented in Figure 6.

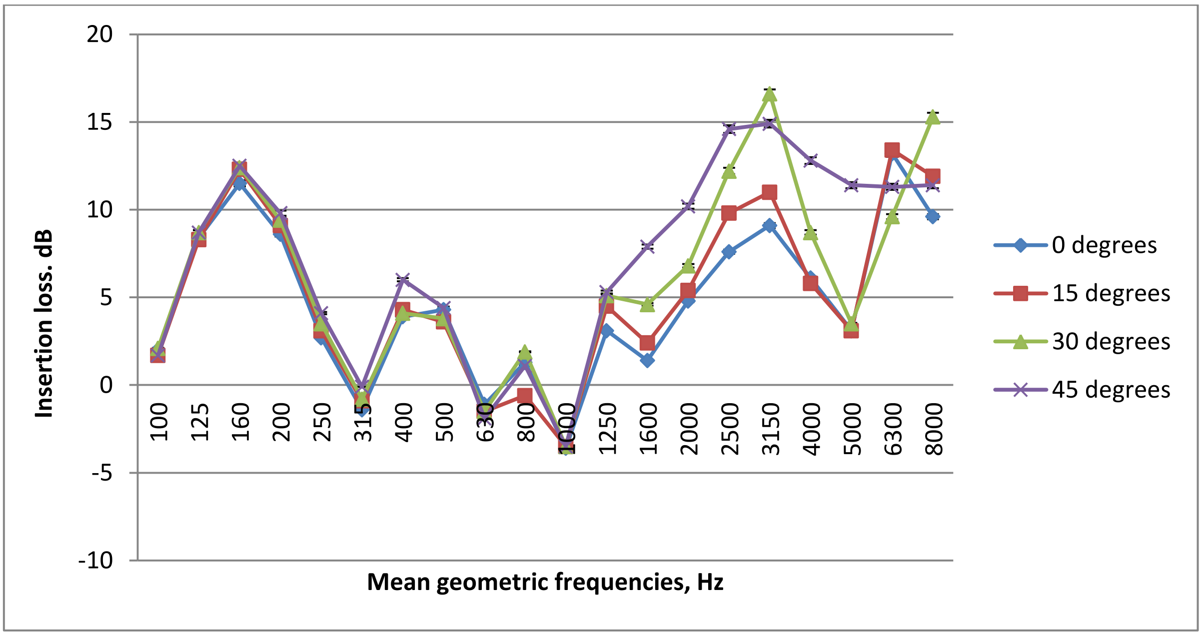

Fig. 6. Noise level reduction in the entire frequency band by the structure with blades covered with polystyrene foam and inclined away from the noise source

The comparison of results with louvre blades inclined towards and away from the noise source showed that at low frequencies from 100 to 630 Hz the noise level reduction is very similar. The noise level reduces at 100-250 Hz and 400-500 Hz frequencies. No significant differences in noise level reduction were observed in terms of blade inclination angle. The most noticeable influence of blade inclination angle was observed at 1 250 Hz frequency. As seen from the graph, the bigger blade inclination angle results in bigger noise level reduction. The noise level reduces in high frequency band from 1 250 to 8 000 Hz. The most noticeable noise level reduction of 16 dB was observed at 3 150 Hz frequency when the louvre blades were inclined at 30° angle. At 8 000 Hz frequency and 30° angle the noise level reduced 15 dB.

The calculated values of sound insulation R_w in dB and equivalent noise level reduction L_{Aeq} in dB(A) are presented in Table 2.

Table 2. Sound insulation R_w and equivalent noise level reduction L_{Aeq} with louvre blades covered by polystyrene foam

Louvre blade inclination angle	Frequency, Hz							Sound insulation R_w	Equivalent noise level reduction L_{Aeq}, dB(A)
	63	125	250	500	1000	2000	4000		
0°	12.6	24.0	7.8	5.4	4.8	10.4	15.9	8	5,4
15° towards the source	12.8	24.4	7.8	5.3	4.5	10.1	15.0	8	5,2
30° towards the source	13.0	24.2	7.9	5.4	4.1	8.9	11.7	7	5,2
45° towards the source	13.3	24.7	8.0	5.5	3.8	10.3	9.4	8	5,6
15° away from the source	12.7	24.4	7.8	5.4	4.8	11.0	14.1	8	6
30° away from the source	11.3	25.1	9.0	6.0	3.5	10.8	13.8	8	6,8
45° away from the source	11.6	25.1	9.3	6.0	3.1	15.3	14.1	8	8,4

It should be noted that bigger equivalent noise level reductions were observed with louvre blades turned away from the noise source. In this configuration the equivalent noise level reduction was more noticeable at bigger inclination angle. In the configuration of louvre blades turned towards the noise source no noticeable equivalent noise level reduction was observed at different inclination angles.

When covered with glass wool ISOTEC KVL on one side the blade thickness was 40 mm and the gaps between the blades were 875 mm. Noise level reduction achieved by the structure with blades inclined towards the noise source at 0º, 15º, 30º, 45º angles are presented in Figure 7.

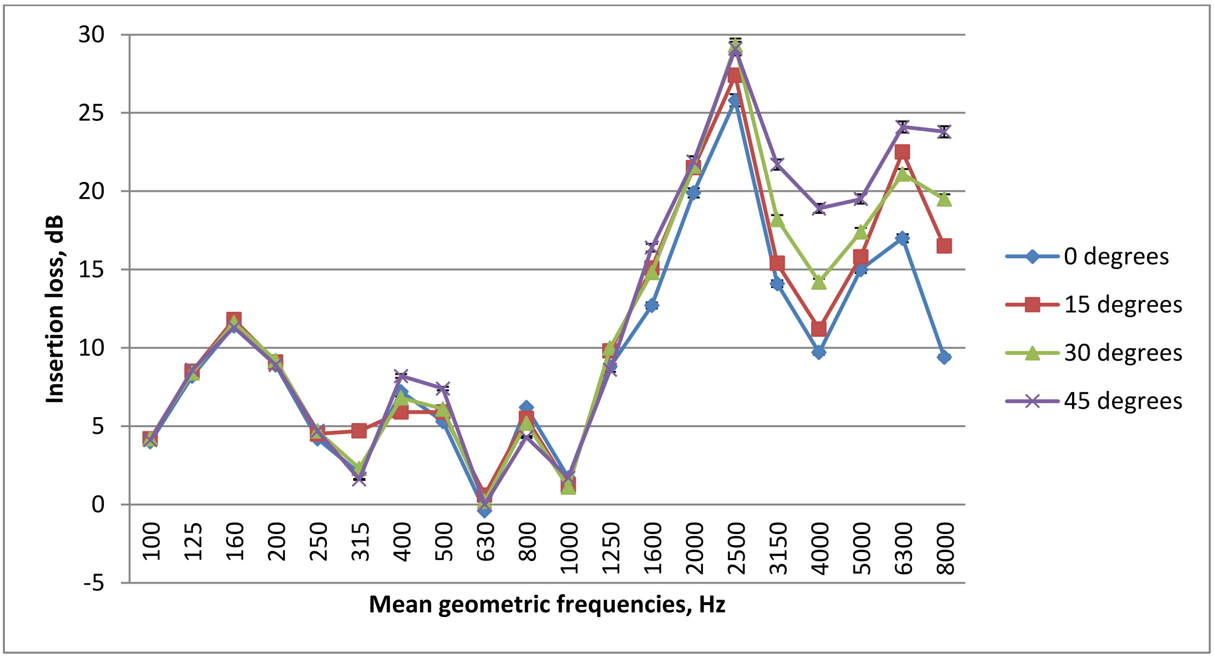

Fig. 7. Noise level reduction in the entire frequency band by the structure with blades covered with glass wool slab ISOTEC KVL and inclined towards the noise source

At low frequencies the blades covered with polystyrene foam demonstrate noise level reduction properties similar to those of blades not covered by any acoustic material. In low and average frequency band from 100 to 1 000 Hz no significant noise level reduction was observed with louvre blades inclined at different angles. In low frequency band the biggest noise level reduction of 12 dB was recorded at 160 Hz frequency. The graph illustrates that the biggest noise level reduction due to wave diffraction occurs in high frequency band from 1 250 to 8 000 Hz. The noise level reduction differences resulting from the change of blade inclination angle is also the most noticeable in high frequency band. At 2 500 Hz frequency the noise level reduces the most, namely 28 dB, at 30º and 45º blade inclination angles. In 3 150-8 000 Hz frequency band the noise is attenuated the best by louvre blades inclined at 45º angle. The least noise level reduction is observed at 0º angle.

Noise level reduction was also measured with louvre blades inclined away from the noise source at 0°, 15°, 30°, 45° angles. The results are presented in Figure 8.

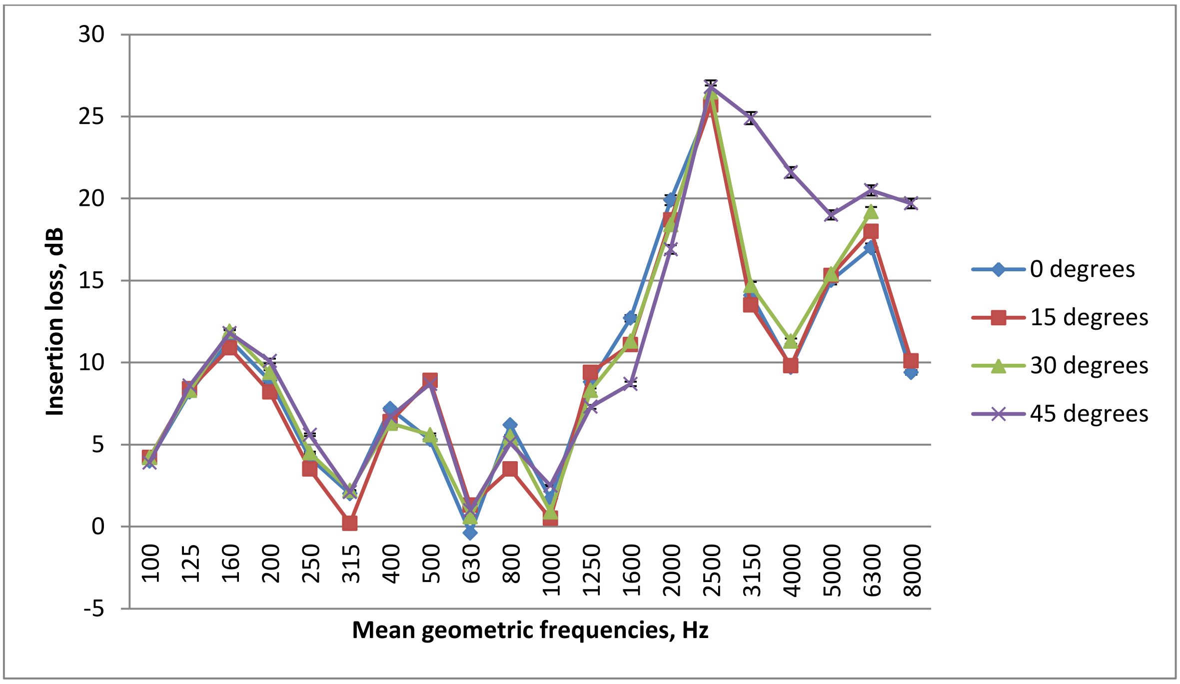

Fig. 8. Noise level reduction in the entire frequency band by the structure with blades covered with glass wool slab ISOTEC KVL and inclined away from the noise source

The test results showed no difference in noise level reduction in low frequency band from 100 to 400 Hz with louvre blades inclined away from the noise source. The best noise level reduction result of 12 dB was recorded at the low frequency of 160 Hz. The graph illustrates that the biggest noise level reduction due to wave diffraction occurs in high frequency band from 1 250 to 8 000 Hz. In high frequency band from 1 250 Hz to 8 000 Hz the difference cause by louvre blade inclination angle was observed. The graph below illustrates that the best result is obtained with louvre blades inclined at 45° angle, i.e. at 2 500 Hz frequency the noise level reduction was 26 dB. Similar results were given blades inclined at 30^0, 15^0 and 0^0 angle.

The calculated values of sound insulation R_w and equivalent noise level reduction L_{Aeq} are presented in Table 3.

Table 3. Sound insulation R_w and equivalent noise level reduction L_{Aeq} with louvre blades covered by glass wool slab ISOTEC KVL

Louvre blade inclination angle	Frequency, Hz							Sound insulation R_w	Equivalent noise level reduction L_{Aeq}, dB(A)
	63	125	250	500	1000	2000	4000		
0°	10.1	26.0	9.7	6.6	7.6	17.1	16.5	10	10,8
15° towards the source	9.4	24.1	11.4	6.8	5.0	19.0	19.5	9	11,6
30° towards the source	9.1	22.9	12.3	5.4	6.3	19.7	21.8	9	12,0
45° towards the source	10.6	23.0	13.0	7.0	6.8	18.8	27.7	9	12,4
15° away from the source	9.8	26.4	9.2	6.4	6.7	17.4	18.3	10	10,8
30° away from the source	9.7	24.0	10.1	7.5	6.7	15.9	22.0	9	11,2
45° away from the source	9.9	23.1	13.1	6.4	6.7	15.8	24.5	9	11,6

Differences in noise level reduction were observed both with louvre plates inclined towards and away from the noise source. The lowest noise level reduction values were recorded at 0° angle, whereas the biggest noise level reduction was observed with louvre blades inclined at 45° angle. We also observed that the configuration of the structure with blades turned towards the noise source is more effective in terms of noise level reduction. With the blades turned towards the noise source and inclined at 15º, 30º and 45º angles the noise level reduction was bigger by 1.5 dB compared to the blades turned away from the noise source.

4 Discussion

Test result show, that all tested constructions low frequency noise from 100 to 500 Hz reduces similar. Using light, thin materials, low frequency noise is slightly reduced. Studies have found that the best low frequency noise reduction is at 160 Hz, where using different constructions noise level is reduced to 12 dB, by using not covered construction to 8 dB. Due to wave interferention, reduction of noise level from 200 to 1000 Hz is lower. Construction, which blades are covered with glass wool slab ISOTEC KVL reduces noise at these frequencies to 7 dB, covered blades with polystyrene foam from 7 to -5 dB at 1000 Hz, this means, that sound wave going through the gap between blades interfere and amplifies noise level. Test results of not covered construction also identify the strengthening of the sound level from 630 to 2000 Hz, which amounted to -5 dB. Studies have found, that all constructions best reduces high frequency noise. This is because that 1000 Hz sound wavelength closer to 30 cm, which means that wave do not circumvent construction blades and is absorbed. Test results show, that construction, which blades covered with glass wool slab ISOTEC KVL, reduces noise level to 29 dB at 2500 Hz, construction covered with polystyrene foam best reduces noise level to 16 dB at 3150 Hz. All test results show, that construction covered with thin, light noise absorbing materials best reduces high frequency noise, which is emitted by engineering equipment for which such construction offering to apply

5 Conclusions

1. The difference in noise level reduction resulting from the blade inclination angle with all types of tested acoustic materials was observed only at frequencies above 1 250 Hz. In high frequency band there was also the biggest noise level reduction, partly as a result of wave diffraction. In case of the structure with blades not covered by any acoustic material the biggest difference in noise level reduction depending on the blade inclination angle was observed in 2 500-4 000 Hz frequency band: the best noise level reduction result of 6-7 dB was obtained with blades inclined at 45º angle and the worst result was obtained at 0º angle.
2. With the blades covered by 15 mm-thick glass wool slabs ISOTEC KVL and inclined towards the noise source the biggest difference in noise level reduction in terms of blade inclination angle was recorded at 4 000 Hz frequency: blades inclined at 45º angle insulated the noise by 9 dB better compared to the blades inclined at 0º angle. When blades were inclined away from the noise source, the biggest difference in noise level reduction between blade inclination angles of 0º and 45º was 12 dB at 4 000 Hz frequency.
3. The comparison of equivalent noise reduction levels of the structures showed that the best result was obtained with ISOTEC KVL slabs. Blades inclined at 45º angle rendered the biggest noise level reduction of 12.4 dB. It should be noted that blades inclined towards the noise source produced a 1 dB bigger reduction of noise level compared to the blades inclined away from the source. A bigger reduction in noise level was also observed at bigger inclination angles of the blades.

4. With the blades covered by 20 mm-thick polystyrene foam the best noise level reduction result of 8 dB was obtained when the blades were inclined away from the source at 45º angle. With the blades inclined towards the noise source at 45º angle the noise level reduction was 2 dB less. In both cases a bigger reduction in noise level was recorded at bigger inclination angles of the blades.

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