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Theoretical End Experimental Evaluation of Perforations Effect on Sound Insulation

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Abstract. To design a sound-absorbing panel, it is important to identify factors that affect the maximum sound absorption of low, middle and high frequency sounds. Perforation effect is very important for the noise-reducing and noise-absorbing panels. Perforations are often used for sound reduction. Experimental data shows that the perforation is very effective to absorb low-frequency noise. In the presented study, influence of perforation coefficient of noise reduction was analyzed with theoretical and experimental methods. The experiments were conducted in noise reduction chamber using an perforated construction with glass wool filler. Sound reductions index of 15 dB indicates good acoustic properties of the panel.

Keywords: perforation effect, absorption, sound absorption coefficients, porous material, low-frequency sound, holes diameter.

Conference topic: (e.g.) Environmental protection.

Introduction

Each typical perforated panel consists of surface and located on it apertures. The radius of the holes perforation varies from 1 mm to 1 cm for macroperforated panel, smaller radius determines microperforated panel; if radius exceeds 1 cm – it's perforated panel. Area hole is important because it determines the resonance frequency of absorption of perforated panels. Small diameter holes promote better absorption. The absorption decreases with increasing of open space of panel. Different types of area holes and percentage of perforation are shown in Fig.1 (Atalla, Sgard 2007).

Engineering approach for the analysis of plywood/fibreglass perforated panels is used for the linearisation of the frequency response of medium size rooms below 200 Hz (Panteghini *et al*. 2007).

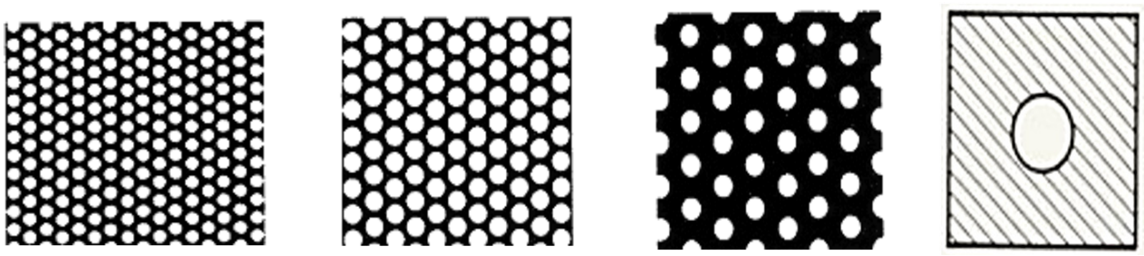


Fig.1. Different types of area hole (Schultz 1986)
46% hole with open area; b) 37% open area; c) 23% open area; d) 10% open area

Dr. Schultz has identified in his works a significant amount of materials, that work with buzz and rattle sound. Holden M., pointed out various types of perforations, which are described in his work. Examples of different types of perforation are presented in Fig. 2 (Holden 2015).

To assess the perforations effect, multiple factor transparency index (TI), sound reduction index (R_w), showns the amount of dB which perforation plate can reduce sound.

For further improvement of properties, perforated plate design is used in the construction of the panels. Porosity of the perforated plate and density of porous material would significantly affect the acoustic impedance and sound absorption coefficient of the panel. In this case high acoustic absorption is achieved. Acoustic absorption of multilayer materials is better with perforated plate (Rozli, Zulkarnain 2010).

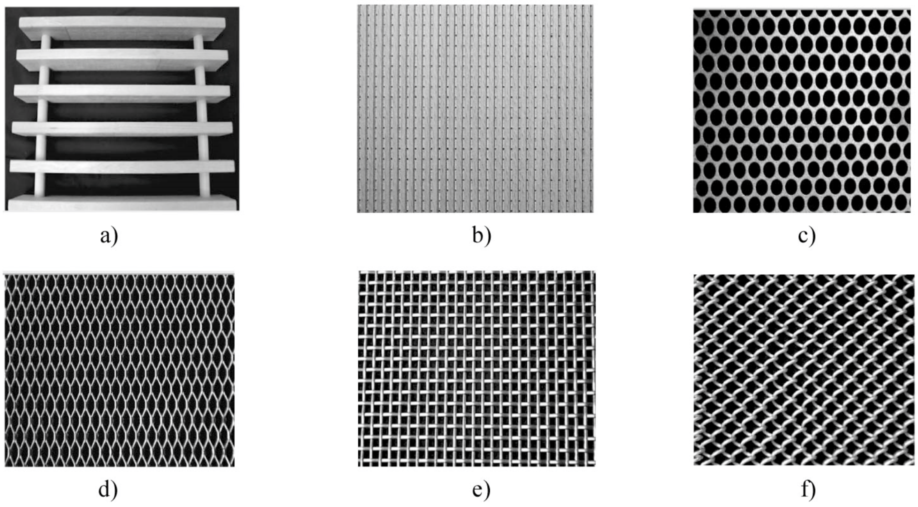


Fig. 2. Examples of different types of perforation
a) Open area wood slate system 70%; b) open area wood slate system 4%;
c) open area expanded metal 58%; d) expanded metal 66%; e) coiled metal 51%;
f) coiled metal 66% (Holden 2015)

Qian *et al.* (2013) conducted experimental study by reducing the perforation diameter to less than 100 mm in order to get larger value of acoustic resistance. It is found that half-absorption bandwidth of 3–4 octaves has the peak absorption higher than 0.85. The results are promising in terms of practical purposes but facing difficulty in manufacturing technique to fabricate such tiny holes (Qian *et al.* 2013).

Perforated panels with absorptive material and air space backed have been wildly used in architectural acoustics and noise control problems.

Creating perforations on the sound-insulating layer increases the absorption coefficient in the case of formation of the absorbing layer of porous, spongy and mixed (porous-spongy and porous-fibrous) structure.

Past research work has shown that when the holes were reduced to such a small size, the panel acoustic resistance increased tremendously. As a result the ratio between its acoustic resistance and its acoustic mass increases as well. With a high acoustic resistance and high resistance-to-mass ratio, the perforated panel itself forms an efficient sound-absorbing construction without the use of any porous material.

Factors, which affect the sound absorption coefficient, are the thickness of the facing, diameter of the hole, distance between two holes, percentage perforation, types and thickness of the backing materials, and thickness of the air space.

Munjal and Thawani (1997) theoretically analyzed the effect of the percent open area of a perforated panel facing a highly porous fibrous material. For highly porous fibrous material 4.9% percent open area affects about 10% of the open area is a good compromise between acoustic productivity and mechanical strength.

At the present time, and for aesthetic reasons, perforated panels with perforation coefficients lower than 10% are preferred, leading to a remarkable degradation of the absorption spectrum of the whole set (Pfretzschner *et al.* 2004).

Effect of perforated size and air gap thickness on acoustic properties of absorption by coir fibre was studied by Rozli Zulkifti and Z. Zulkarnain (2010). The results show that the panel has a high potential to perform as a commercial product in sound absorption applications for absorbing different acoustic frequency by changing the settings on perforated size and air-gap thickness on the panel (Rozli, Zulkarnain 2010).

A compact expression for acoustic impedance of perforated plates indicated that the influence factor included the thickness, hole radius, hole pitch and porosity of the perforated plates and air contained in the holes. For porous material, complex wave propagation constant and characteristic impedance could be expressed in terms of the flow resistivity, wave number, air density and sound frequency (Rozli, Zulkarnain 2010).

is described in detail in the work D. Borelli. protective layers may have a dual function, which works like a mere support to the porous sound-absorbing material or operates like a real absorbent panel according to the open area (Borelli, Schenone 2005).

Anechoic chamber is a room designed to be echo free field due to complete absorption and reflection of sound. Sound absorption is obtained by lining the wall, ceiling and floor of the room with absorbent material (Zulfian, Lindawati 2014). Anechoic chamber was designed fully according to acoustics laws and customers requirements (Rusz 2015). Anechoic chamber can be used for absorption reflections electromagnetic waves. Anechoic chambers are mostly utilized in the microwave region. A model for pyramidal RF absorber has been developed by B.-K. Chung and Chuah (2003).

Precision of measurements carried out in the shielded anechoic chamber substantially depends on a shielding level and anechoic factor. The anechoic factor is determined according to the used radar absorbing coating characteristics (Dobychina *et al.* 2013).

Perforated panel absorber is for future use in sound insulation and sound absorption. It is very important in study of perforation effect of micro-perforated panels. Consequently, aim of our work was to explore perforation effects.

Methodology

Research was conducted in a anechoic chamber in Vilnius Gediminas Technical University (VGTU), Department of Environmental Protection. The laboratory chamber consists of two rooms, separated by a double wall and a neighboring room intended for measuring equipment, anechoic chamber plan (see Fig. 2). Room 1 is conditionally called a source (transmitting sound) room, room 2 – a target (receiving sound) room. The entire surface area (walls, flooring, ceiling, partition) of the noise-suppression chamber interior totals 70 m and is covered with 0.25 m layer boards of cut acoustic foam (0.15 m cutting step) of a conical form. Area S of separating element 10, 00 m^2 source room volume 35 m^2 receiving room volume: 35.00 m^2 (e. g. see Fig. 3).

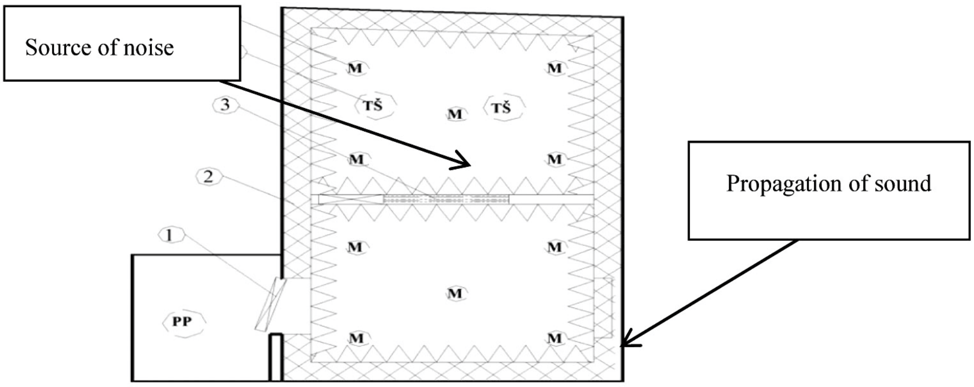


Fig. 3. Situation plan of the noise-suppression chamber: a) view from above the noise-suppression chamber: 1 – door; 2 – chamber partitions covered with foam; 3 – cage for mounting the study samples; 4 – positions of noise sources (TŠ); 5 – microphone positions (M); PP – data-recording-and-processing room (Grubliauskas, Butkus 2009)

International Standard specifies methods for measuring the sound pressure levels on a measurement surface enveloping a noise source (machinery or equipment) in an anechoic room ISO 3745:2012. The laboratory chamber consists of two rooms, separated by a double wall and a neighbouring room intended for measuring equipment. Room 1 is conditionally called a source (transmitting sound) room, room 2 – a target (receiving sound) room. The instrument has two measuring channels; therefore, it can record noise at different points using two microphones at a time. One microphone is positioned in the source room, another one – in the target room. For instance a simple method working with two microphones (the socalled microphone doublet method). It is simple and correctly working at low frequencies but it needs to have a sound source (i.e. a loudspeaker) mounted at a sufficient distance (Grubliauskas, Butkus 2009). Example condition in sound propagation and a source room (e. g. see Fig. 4, 5).

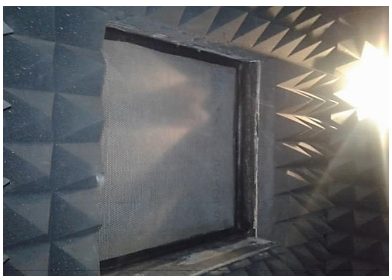


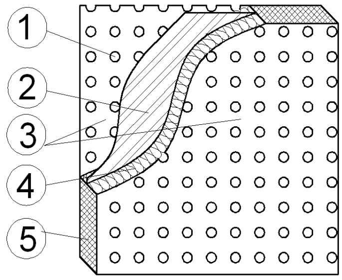
Fig. 4. Example condition in sound propagation room

Fig. 5. Example condition in a source room

In our researches we tested plate with perforations of different diameters and a layer with glass wool (e. g. see Fig. 6). The fiber materials (e.g. glass wool fiber) are often used as thermal isolation in air and building industry. Glass wool is an insulating material made from fibers of glass arranged using a binder into a texture similar to wool. Glass wool insulation is one of the most widely used forms of insulations world-wide because of its thermal and acoustic properties, light weight, high tensile strength.

In an anechoic chamber sound is spread from the source to the propagation room. Perforated plate was made of tin shield (2 mm thickness, hole diameter 0.6 mm, distance between the holes 0,8 mm with fiberglass inside) Perforated plate acted as a top layer of the material for sound absorption (e. g. see Fig. 6).

a)



b)

Fig. 6. A perforated tin shield with a filler: a) view of the construction;
b) layer of the construction

The sound reduction index is a scalar representation of the amount of sound energy absorbed upon striking a particular surface. According to the international standard LST EN ISO 10140-2 the sound reduction index is found from:

Ten times the common logarithm of the ratio sound power W_1 that is incident on a test element to the total sound power radiated into the receiving room if in addition to the sound power W_2 radiated by the test element the sound power

$$R = 10 \lg \frac{W_1}{W_2}, \quad (1)$$

R is expressed in decibels.

In general the sound power transmitted into the receving room consist of the sum of several components. Also in this case, under the assumption that there are diffuse sound fields in the two rooms, the apparent sound reduction index is evaluated from Equation.

$$R = L_1 - L_2 + 10\log\frac{S}{A}, \quad (2)$$

L_1 average sound pressure level in the source room; L_2 – average sound pressure level in receiving room; S area of the free test opening in which the test element is installed, in square metres; A equivalent absorbtion area in receiving room in square metres equivalent absorption area A is evaluated from

$$A = \frac{0.163V}{T}\left[\mathrm{m}^2\right], \quad (3)$$

$V =$ receiving room volume m^3

T = reverberation in receiving room

Transparency Index (TI) which is calculated by the formula:

$$TI = nd^2/ta^2 = 0.04\ \mathrm{P/1rta}^2, \quad (4)$$

where: n = number of perforations per sq in; d = perforation diameter (in); t = sheet thickness (in); a = shortest distance between holes (in); $a = b - d$, where b = on-center hole spacing (in); p = percent (not fractional) open area of sheet.

The formula is valid for either straight or staggered perforations. An approximation for the value of a, when you do not know the value of b, is:

$$a = d[(\mathrm{const.}/P1/2) - 1]. \quad (5)$$

The value of the constant is 9.5 for staggered and 8.9 for straight perforations.

We can predict from the value of TI the amount by which sound waves at the very high frequency of 10 kHz are attenuated in passing through the sheet, according to the curve in Figure IS, and from this we can develop a curve for the attenuation at lower frequencies (Schultz 1986).

Results

Experiments with measurement sound installation properties of perforated plate were carried out. Dependencies of differentd range frequency with sound reduction index were found (see Fig. 7). Our results were compared with reaserches of other authors. Results on transparency index were shown.

It was found that sound reduction index at low frequencies also increases to 22,7 dB at frequency 125 Hz. Sound reduction index decreases at frequencies from 200 to 315 dB and it has minimum value 6,7 dB. sound reduction index at middle frequency exponential growth from minimum 6.6 to maximum 21,8 dB at frequency 2500 Hz. At hightfrequencies most effective sound absorption was 25,2 dB (at frequency 5000 Hz). Sound reduction index in our study was 15 dB.

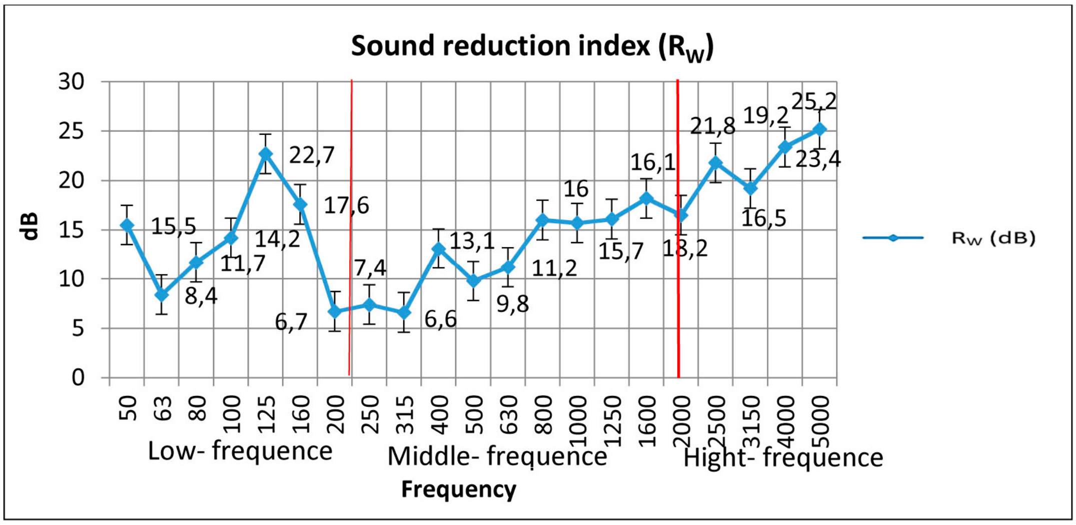


Fig. 7. Example condition in sound propagation room

Other authors described the perforation effect. Their research showed that a sound reduction index increase at low frequencies to 20 dB and approaches to 0 at high frequencies. For the case of the unbaffled perforated plate, the effect of perforation is almost independent of frequency in the fundamental and corner mode regions Data from the MathML showed that index of sound absorption increases at high frequencies. It was also determined that the sound show that sound radiation was reduced by increasing the perforation ratio, constant perforation ratio, the radiated sound can be further reduced by reducing the hole size. The effect also depends on the plate thickness and dimensions. For only 10 % perforation ratio and 10 mm diameter holes, the sound radiation can be reduced by 10–15 dB at low frequencies, which illustrates the effectiveness of perforation as a noise control measure. An approximate formula to predict the effect of perforation has also been proposed which can be used for frequencies up to half the critical frequency (Putra, Thompson 2010). His research as well as our work showed that sound redaction index increased at low frequencies (in our work it was 22, 7 dB) and then increases in the edge mode region, as the frequency increases which corresponds to our research.

When the thicknesses of sound insulation property of Al–Si closed-cell aluminum foam sandwich panels foam sandwich panels are 12, 22, and 32 mm, the corresponding weighted sound reduction indices (R_W) are 26.3, 32.2, and 34.6 dB, respectively, the rising trend tempered. The sound reduction index (R_w) of of Al–Si closed-cell aluminum foam sandwich panels foam sandwich panels bare was investigated at difernt freulaencies (100-4 000Hz) It was found that sound reduction index R small under low frequencies, lage under hight frequencies it depend from triecnes and density, material. The good instalation property lighth mass material. Speciement with trickness of 20 cm and density of 0,51 g/ cm^3 are 30,08 dB and 33 dB which demonstrated good instalation property lighth mass material (Yu *et al.* 2007). Higher sound redaction index can be explained by the fact that the use of materials have a lower density than our materials fiber glas 2,05 0,51 g/cm^3 sttell, 7,8 g/ cm^3. It may also related to the fact that this aluminum foam bare plate without holes.

Transparency Index as an indicator of how easily sound can pass through a particular sample of perforated metal at high frequencies. Transparency Index 195 showed that the perforation reduces sound at percent open area 40% the 10-kHz-attenuation has increased to 6 dB. This is a fairly high sound insulation. Therefore, this perforation effectively absorbs noise. According to the research of Dr Schultz, The value of TI increases as the hole size and the number of holes per sq in increases and as the thickness of the sheet and the distance between holes decreases. For values of TI less than 2000, the sound transparency diminishes rapidly, and the perforated metal blocks the passage of sound.

Conclusions

1) It was determined the dependence percent perforation for the installation low-frequency sound. Low percentage of perforation and lower holes diameter promote better sound absorption.

2) Sound reduction index decreases at low frequencies 125Hz and there is a tendency for exponential growth at high frequencies. It was also noted in other authors who worked with perforated panels. This suggests that perforated panels are effective for the insulation low-frequency sound 125Hz.

3) Sound reductions index of 15 dB indicates good acoustic properties of the panel.

4) The influence of thickness, density of the sheet, mass of materials on were determined.

4) Transparency Index showed that the perforation plate reduces sound by 6 dB.

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