Acoustic study of multi-layered microperforated elements for fibreless noise control applications

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Abstract. Recently fibreless solutions have become a trend in the design of sustainable and environmentally friendly duct silencers. Hereby microperforated panels have been proven to provide adequate performance for the substitution of unfavourable fibrous material layers commonly used in mass-produced silencers. This paper presents an acoustic study of microperforated elements aimed for an effective and eco-friendly heating, ventilation, and air conditioning (HVAC) duct silencer. Several microperforated sheet metal panels have been experimentally tested in a variety of layered configurations in order to maximize the sound absorption coefficient in operational frequency range. The optimal solution is implemented in the design concept of a novel fibreless HVAC silencer presented in this research. The results of the study demonstrate the appropriateness of the double-layered microperforates for a duct silencer as well as for a variety of Noise, vibration and harshness (NVH) implementations were potent noise absorption is aimed.

Keywords: microperforated element, absorption coefficient, HVAC silencer, fibreless.

1. Introduction

Noise control devices have been extensively used in various technical fields: e.g. automotive and aeronautical industries, construction engineering, HVAC systems, etc. In the recent decade, a requirement for eco-friendly noise cancellation materials in flow ducts (e.g. HVAC ducts, automotive exhaust silencers etc.) has been highlighted. The replacement of fibreless materials with non-fibreless materials has become a trend. One of the proposed materials with great potential is microperforated element typically provided in sheet metal panels. Variety of microperforated panels (MPP) have been widely applied for almost two decades being first introduced by Maa already in 1970s [1-3]. Maa proposed that the perforations are to be reduced to submillimetre level in order to provide sufficient acoustic resistance. He also developed analytical models for predicting acoustical properties (equivalent electrical circuit model) and pointed out that MPP’s can be tuned for wide frequency band, thus suitable for variety of applications.

The properties and application of microperforations are studied extensively also in TalTech laboratory of technical acoustics [4-8]. A number of studies are mainly focused on applications for internal combustion engine exhaust silencers. Different microperforations have been studied with varying aperture geometry and pattern as well as porosity variations. Also, the authors have performed...
investigations on the endurance and reliability for clogging of the microperforated tube sections in operating IC engine applications [6–7], successfully demonstrating the suitability of the solutions. Multy-layer MPP set-up has been investigated also in past [9]. A few alternative configurations of aperture for MPP are investigated and presented in article [10]. The current study is focusing on the experimental determination of the properties of single and double layer MPP configurations using commercially available Acustimet® sheets produced by Swedish company Sontech International AB [11]. A recently published study [12] on the acoustical performance of Acustimet® aiming vehicle cabin noise suppression exhibits the potential. The main interest hereby is to investigate the opportunities to replace the commonly used fibrous material layers in mass-produced HVAC silencers with the MPP to achieve acoustically effective, fibreless and eco-friendly silencer concept.

2. Experimental studies
The experimental studies were carried out in TalTech laboratory of technical acoustics. The key parameters of the silencer elements were acoustically determined by using dedicated test facilities. The aim of this study is to determine sound absorption performance characteristics in variety of layouts for two different commercially available materials. A third MPP material sample was also included into the study for reference purposes. The materials tested, are shown in figure 1.

Figure 1. Material samples (D=28 mm) tested. a) material A; b) material B; c) material C

Material A and B are commercially available under the brand name Acustimet® produced by Swedish company Sontech International AB, the third specimen is custom-made microperforated panel. The characteristic parameters for the different materials are shown in table 1.

|          | Material A | Material B | Material C |
|----------|------------|------------|------------|
| Aperture dimensions | 1,7x0,1 mm | 4x0,1 mm   | d 0,5 mm   |
| Aperture shape      | Slit shape  | Slit shape  | Orifice    |
| Material used       | Aluminium alloy | Aluminium alloy | Steel alloy |
| Specific weight     | 2,6 kg/m²  | 1,67 kg/m² | 3,54 kg/m² |
| Porosity            | ~1%        | ~3%        | ~18%       |

Materials A and B were also studied by microscopy (see figure 3) to determine the aperture geometry and porosity. For Material C it was not necessary because of its simple orifice shaped apertures. As we can observe from figure 3, the materials A and B have a slit type aperture.

Figure 2. One-port measurement set-up to experimentally determine absorption coefficient of the materials [14].
One of the most important parameters for characterization of noise attenuation performance is acoustic absorption coefficient which determination is discussed below. The widely used method to determine the absorption coefficient of materials is the impedance tube method following ISO 10534-2:1998. The specimen size is only determined by the cross-sectional area of the test tube (see figure 2) [13]. The material specimen is fitted into the rigidly closed end of the tube. By applying excitation noise from the electro-dynamic driver from the other end of the tube and by measuring the acoustic signals from two microphones, it is possible to calculate the absorption coefficient of the material tested. The plane wave acoustic pressures at two microphones separated by distance $s$ can be expressed as [13]:

$$p_1(f) = p_{1+}(f) + p_{1-}(f)$$

$$p_2(f) = p_{1+}(f)\exp(-ik_s) + p_{1-}(f)\exp(ik_s),$$

where $p$ is the acoustic pressure, $f$ is the frequency, $k = \frac{2\pi f}{c}$ is the wave number, $c$ is the speed of sound, - and + denote the pressure waves propagating in negative and positive direction along the tube axis. The reflection coefficient at microphone 1 is defined as [13]:

$$R(f) = \frac{p_{1-}(f)}{p_{1+}(f)}.$$ 

It can be shown that:

$$R(f) = \frac{H_{12}^f - \exp(-ik_s)}{(\exp(ik_s) - H_{12}^f)},$$

where $H_{12}^f = p_2/p_1$ is the transfer function between induct mounted measurement microphones 1 to 2. Then the absorption coefficient of the material is calculated as [13]:

$$\alpha_s (f) = |1 - R(f)|^2.$$ 

According to the impedance tube diameter of 24 mm, the cut-of frequency is 8376 Hz, and the observation range is chosen from 200 Hz to 8000 Hz which is determined by microphone separation ($s=16mm$). For the experiment, the investigated material is placed on to the tube with varying distance from back wall X1. The distance X1 is set from 0 mm to 50 mm with single layer set-up (see figure 3). With double layer set-up, there were placed two MPP in sequence with distances X1 and X2, where...
distance X1 was set 30 mm and 50 mm and distance X2 was varying from 5 mm 50 mm. Experimental equipment and set-up is shown in figure 4.

Figure 4. One-port (impedance tube) test rig configuration: IT – impedance tube (inner diameter 28 mm); M – two 1/4” microphones; D – electro-dynamic drive (sound source); DAQ – data acquisition system; PC – computer; A – excitation signal amplifier.

Experimental tests were carried out using the following equipment:

- two 1/4” prepolarized pressure microphones (G.R.A.S. 40BD),
- four channel DAQ analyser (NI 9234) and USB Carrier (NI USB-9162),
- electro-dynamic driver (BMS 4591),
- excitation signal amplifier (Yamaha AS201).

3. Results

Absorption coefficient tests with MPP were first conducted with varying distance X1 from back wall from 0 mm to 50 mm (see figure 2). The tests were repeated for all three different MPP materials, as shown in figure 1. Comparison results from the impedance tube test are presented in figure 5, where the distance X1 was set to 15 mm from back wall. It is clearly seen that material A and B exhibit higher absorption characteristic than material C. In figure 6 and figure 7 one can observe that by increasing the distance from the back wall, the absorption peak will be moved towards the lower frequencies. The initial back wall distance was set to 0 mm, as that perforated plate is at the far end of the test tube, and in this case the maximum absorption coefficient occurs at 3600 Hz. With distance X1 set to 15 mm, the maximum absorption shifts to around 2100 Hz.

Followingly, two extreme cases were tested, the distance X1 was first set to 30 mm then after to 50 mm and respective results are shown in figure 7, black dotted line and red solid line, respectively. We can observe that the maximum absorption shifts even more to the lower frequencies, 1200 Hz and 900 Hz, respectively. Also, we can see that the second peak appears at higher frequencies with distance set to 30 mm. By setting the X1 to 50 mm a third peak appears in the frequency range studied.

For material C and for single layer set-up, the results are presented in figure 8. Distance X1 was varied between 0 to 15 mm. We can observe much lower absorption performance with higher porosity figures (18% respectively). For other set-ups, material C was excluded from further test with now matching performances with material A and B.

Secondly, the double layer set-up test was conducted with material A and B. The distance X1 was set to 30 mm and was held constant. Hereby the varying parameter was the distance X2 for which the
Figure 5-10. Comparison of test result in impedance tube (x-axis is Frequency [Hz]; y-axis is Absorption Coefficient [-]). In first graph (top left) are compared Materials A (yellow dot line), B (red solid line) and Material C (black dashed line). Absorption coefficient for one micro-perforated plate (material A). Distance X1 is set from 0 mm to 15 mm. Absorption coefficient for one micro-perforated plate (material B). Distance X1 is set from 0 mm to 15 mm. Fourth graph (middle right) is absorption coefficient for one micro-perforated plate (material C). For double layer set-up for material A (lower left) and material B (lower right). Distance X1 was set to 30 mm and distance X2 was varying from 5 to 50 mm.
absorption coefficient results are shown in figure 9. First absorption peak shifts even more to the lower frequencies, appearing at around 900 Hz. Considering in comparison, that the peak-frequency for single panel was at 1200 Hz with distance 30 mm and 900 Hz with 50 mm, we can conclude that with double layer set-up the overall distance (X1+X2) also appears to play key role in the silencing performance. Result for material B are presented in figure 10, and we can see even better sound apportioning performance within much wider frequency range.

4. Conclusions
Sound absorption properties of three fibreless microperforated sheet metal panels in a variety of single- and double-layer configurations are experimentally studied in this paper. The results exhibit the multi-layered material’s suitability for sustainable noise control applications. Further investigation is planned for study different HVAC silencer layouts and configurations, e.g. for concentrically mounted microperforated tubes and for a varied number of expansion chambers.

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