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PU PROBE BASED IN SITU IMPEDANCE MEASUREMENTS OF A SLOTTED PANEL ABSORBER

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In this paper the results of in situ acoustic surface impedance measurements on a slotted /perforated absorber are presented. For this purpose, a pu match probe was used measuring both sound pressure and particle velocity. This novel free field method allows measurements on a large variety of materials and geometries, e.g. flat and curved as installed. The benefit of its high spatial resolution was used to scan the slotted absorber. Measurements were taken each 5mm, allowing to calculate the spatial averaged impedance, the reflection- and absorption coefficients. Color maps of the absorption across the scanned area were also plotted for several frequencies. Finally, an even smaller pu probe was built and used to measure variations of the acoustic impedance inside one of the slots of the absorber.

1. Introduction

A slotted and perforated panel absorber is the subject of investigation of this paper. This absorber is called "Topakustik-eco" and it is manufactured by the Fantoni Group in Italy. According to the manufacturer this absorber can be applied in walls and ceilings. The four commercial types of Topakustik-eco available are obtained by changing the size and spacing of the holes in the perforated panel. More information about the absorber can be found in [1].

The Topakustik-eco behaves like a perforated panel helmholtz absorber. In [2] one can find a simplified model describing its acoustical behavior. In short, the perforated panel is an absorber consisted of a closed cavity, partially filled with porous material, which is closed on the top by a perforated panel. The air in the holes takes the role of a mass vibrating over a spring, which is represented by the volume of air enclosed in the cavity. A mixture of acoustical losses, provided by the porous material, and phase changes, in the reflected pressure, are the causes of acoustical absorption.

The Topakustik-eco has a more complex behavior due to its construction. This complexity creates more resonances (peaks) in the absorption coefficient curve. According to the manufacturer the absorption characteristics of the Topakustik-eco can be changed depending on the mountings

used. The configuration of the absorber, used in this paper, can be seen in Figure 1. It is consisted of the Topakustik-eco sheet over a layer of porous material. This whole structure was applied over a hard surface. Measurements took place very close to the surface of the absorber. Many points were measured along an area of the absorber. Therefore, one can investigate how the absorption of the panel varies in space, and also calculate a spatial average of the acoustical surface impedance, reflection and absorption coefficients.

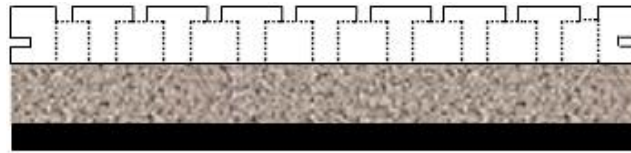


Figure 1. Schematic drawing of the absorber.

The paper structure is as follows. First a description of the measurement and calculations for the impedance is provided to the reader. Results of spatial averages and color maps follow. The last section in the paper shows the variations of impedance inside one slot of the panel, to account for variations in the impedance near the holes.

2. Measurement Procedure

The surface impedance of the perforated panel is measured very locally, with a combined sound pressure and particle velocity sensor. A similar procedure is described in [3]. The behavior of this sensor has been extensively investigated in many other papers: [4], [5] and [6].

The advantage of measuring in situ is that it avoids the use of any special environment, like an anechoic or reverberant room, which can be difficult and expensive to book. It also avoids the traditional impedance tube, which requires the sample to be cut and because of that destroyed.

Measuring close to the surface of the absorber makes the use of a relatively small absorber possible. This is not possible using other techniques like the standard reverberant room or the Tamura method [7], or some other free field techniques [8].

All measurements were done in situ, using the pu match probe, with no protection. This probe is smaller than the usual pu-probe ([3]). The use of the pu match probe allowed measurements 3.5mm close to the surface of the absorber. A photo of the pu match probe, close to the surface of the absorber, can be seen in Figure 2.

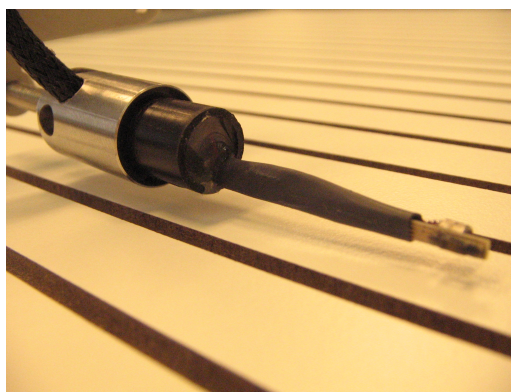


Figure 2. PU match probe close to the surface of the absorber.

The Topakustik-eco has dimensions of 60cm x 60cm. A sample of the total area was scanned in the middle of the absorber. As the absorber is regular across all the area this procedure covers a significant area, and avoids undesirable scattering edge effects. A grid of 5mm was used to guide the

probe along the sample area. This grid is formed by 14x20 points, 5mm distant from each other (See Figure 3), which equals to 280 measurements. All these measurements took less than three hours to be done.

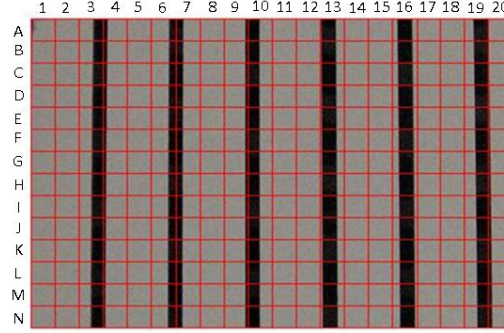


Figure 3. Grid used to scan the absorber.

3. Free field correction

The measurement devices used were the pu match probe, signal conditioner, two channel sound card, and a special loudspeaker that acts like a point-source [9]. In Figure 4 one can see that the distance from acoustic source to the sample is h_s and the distance from pu probe to the sample is h . In the case of these measurements $h_s = 26\text{cm}$ and $h = 3.5\text{mm}$.

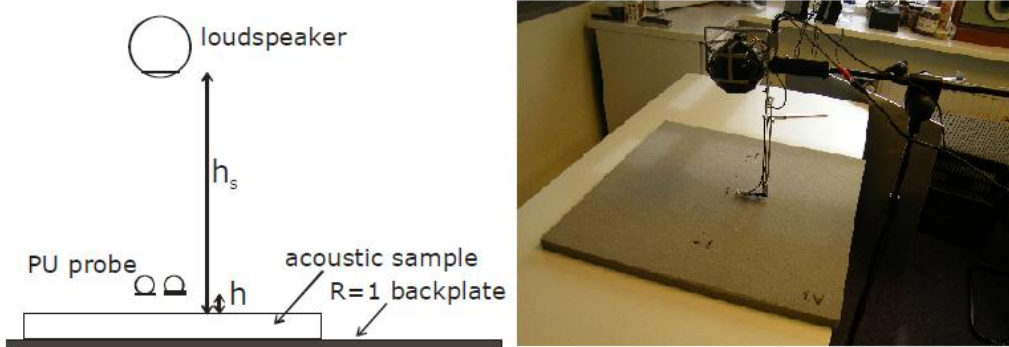


Figure 4. Point source.

The calculation technique of the reflection coefficient involves two measurements. First the free field impedance (Z_{ff}) is measured. This is called the calibration measurement. Note that this is not a standard calibration as described in [10]. This is just the measured ratio of pressure and particle velocity in free field conditions. The second measurement consists in measuring the ratio of pressure and particle velocity close to the surface of the absorber (Z_m).

As said previously the impedance is measured close to the surface of the absorber. In order to calculate the correct surface impedance of the absorber it is necessary to apply a correction model. This way the correct surface impedance is calculated from the measured impedance (Z_m).

The sound pressure and particle velocity, at a point r distant from the source, in $r = 0$, is given respectively in Equations 1 and 2.

$$p(r) = i\rho ck \frac{Q}{4\pi r} e^{-ikr} \quad (1)$$

$$u(r) = \frac{Q}{4\pi} \frac{ikr + 1}{r^2} e^{-ikr} \quad (2)$$

With Q the source strength and k the wave number.

Applying Equations 1 and 2 to the calibration and surface absorber measurements, and in the second case taking into account the incident and reflected waves, one can calculate the reflection and absorption coefficients of the sample with Equations 3 and 4 respectively.

$$R = \frac{\frac{Z_m}{Z_{ff}} - 1}{\frac{Z_m}{Z_{ff}} \left(\frac{h_s - h}{h_s + h} \right) \left(\frac{ik(h_s + h) + 1}{ik(h_s - h) + 1} \right) + 1} \left(\frac{h_s + h}{h_s - h} \right) e^{ik2h} \quad (3)$$

$$\alpha = 1 - |R|^2 \quad (4)$$

4. Results

There are several results that can be taken in this analysis in order to investigate the behavior of the absorber. First of all one can calculate a spatial average of the surface impedance, and then calculate an averaged absorption coefficient. These results can be seen in Figures 5 and 6.

Figure 6 shows the typical behavior of a perforated panel absorber. It's possible to see a high absorption coefficient value around a resonant frequency (main peak - 1400 Hz), and other resonances (peaks) and anti-resonances (valleys).

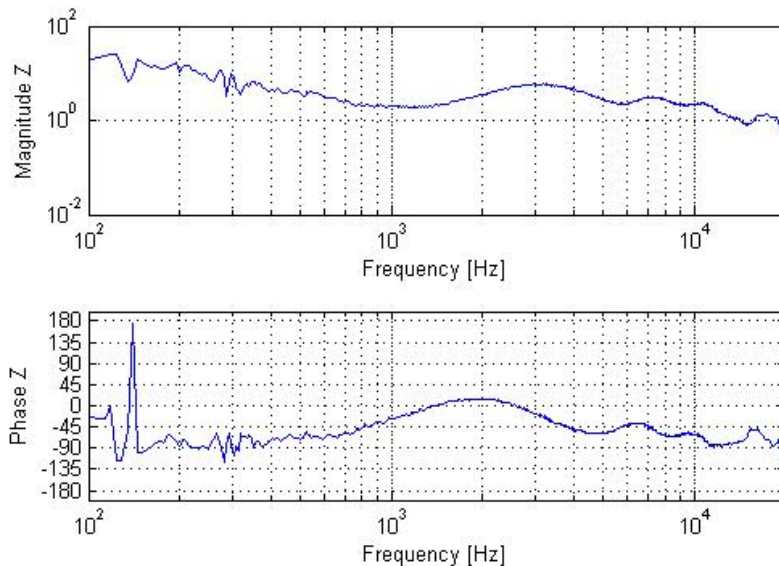


Figure 5. Averaged surface impedance.

Another interesting result is how the absorption coefficient varies in space. In Figure 7 one can see the absorption coefficient of 10 points along the scanned area of the absorber. It's easy to note that the contour of the absorption coefficient is similar for all the points showed (It was also noted for all the other points measured, but not all results are shown here). On the other hand, the value of the absorption increases or decreases depending on the measured point of the grid.

It is suspected that measurements taken above the slots would lead to a higher absorption coefficient, while measurements taken above a hard reflecting part of the perforated panel would lead to a smaller absorption values. In order to investigate this, color maps of the absorption coefficient were plotted (one for each frequency). This way, it's possible to see how the absorption, in a certain frequency, changes across the area of the absorber. These color maps shows the local absorption coefficient and do not describe the absorption of the sample as a whole.

Figures 8 to 12 shows these color maps. What can be seen in all figures, when compared to Figure 3, is that the absorption coefficient increases near the slots of the Topakustik-eco. It is not

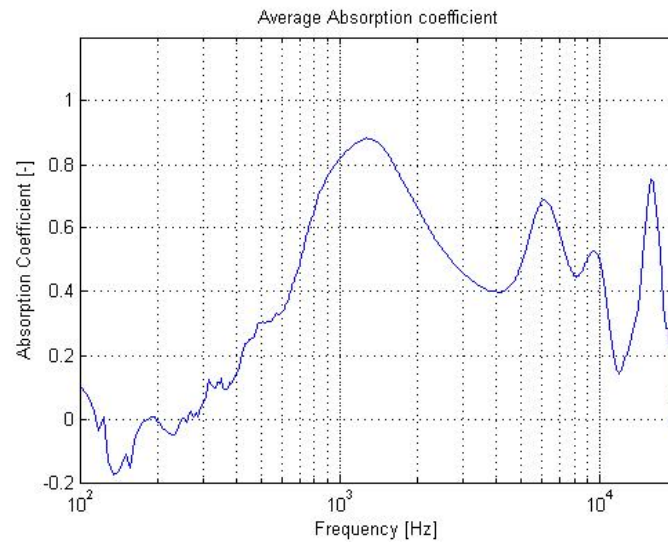


Figure 6. Averaged absorption coefficient.

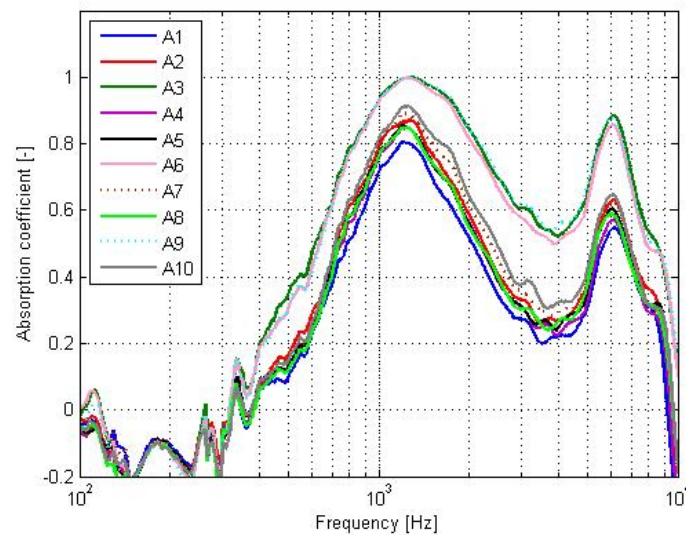


Figure 7. Absorption coefficient (10 points).

possible to see, although, if near the holes there is an increase in the absorption coefficient value. In order to investigate this it's necessary to measure inside the slot, with a smaller pu match probe (see next section). Figures 8 and 9 are color maps of frequencies which are not resonances or anti resonances.

One can also investigate what happens with the color maps of the anti resonance (Figure 10). It is clear that for these frequencies the maximum values of the absorption coefficient are thinner contours over the slots when compared to resonant frequencies color maps.

The resonant frequencies color maps (Figures 11 and 12) shows that, for these frequencies, the maximum absorptions are more spread over the scanned area. In other words the red contours are thicker than for the other frequencies (even for high frequencies). It seems that for resonant frequencies, the acoustical interactions between adjacent holes and slots are bigger than for the non-resonant frequencies.

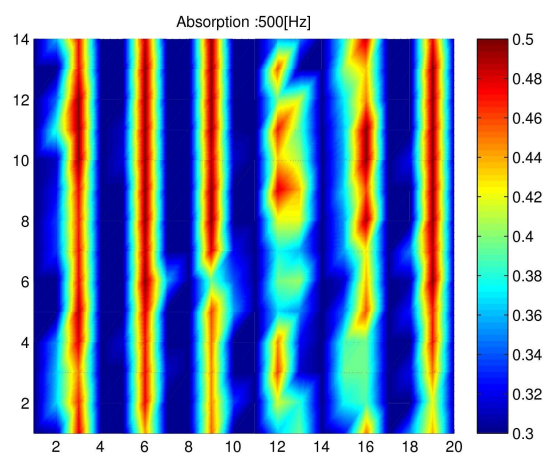


Figure 8. Variation of the absorption coefficient in space (500Hz).

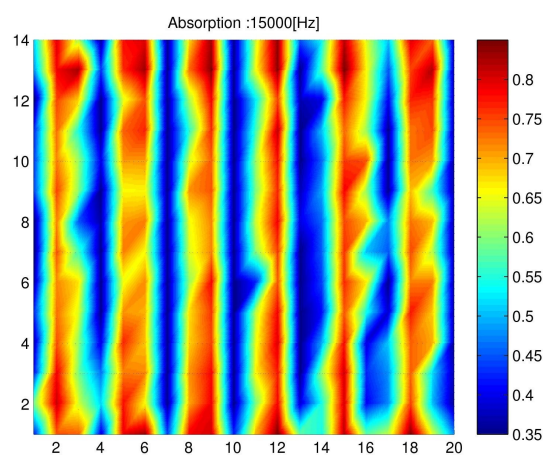


Figure 9. Variation of the absorption coefficient in space (15000Hz).

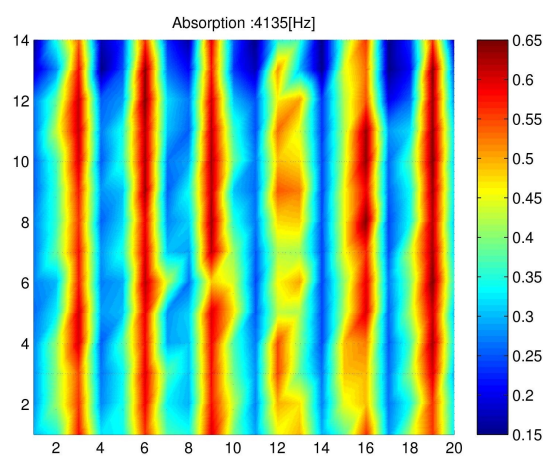


Figure 10. Variation of the absorption coefficient in space (4135Hz - antiresonance).

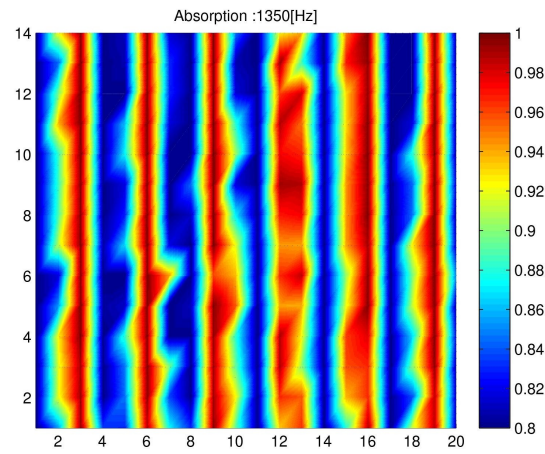


Figure 11. Variation of the absorption coefficient in space (1350Hz - resonance).

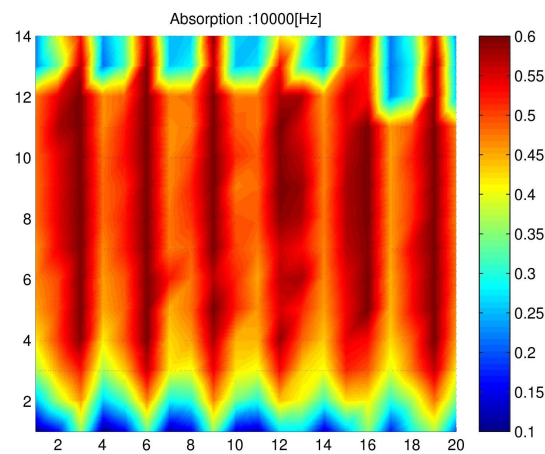


Figure 12. Variation of the absorption coefficient in space (10000Hz).

5. Impedance inside the slot

In order to investigate changes in the surface acoustic impedance, close to the perforations of the absorber, a smaller pu match probe was built. With this probe it is possible to place the pressure and the velocity sensors inside the slot, in order to take several measurements along it (See Figure 13).

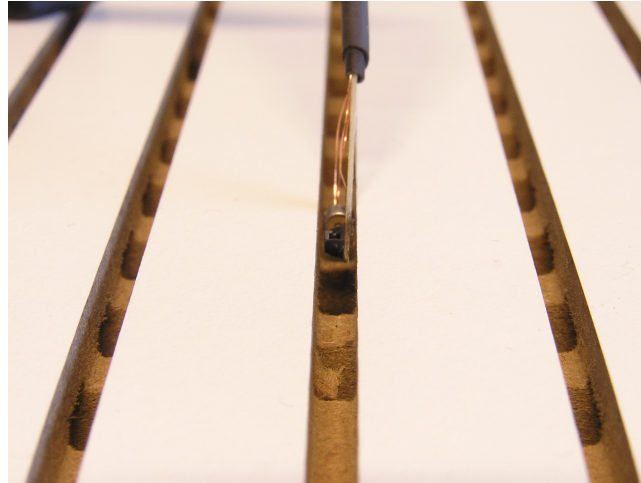


Figure 13. Smaller pu match probe inside the slot.

To scan along one of the slots three different distances (from the perforations to the probe) were used. First it was measured very close to the holes ($h = 1\text{mm}$). After that, measurements took place near the entrance of the slot. For last, measurements were taken at the same distance of the previous measurements showed in this paper. This last one was used only for comparison with the former measurements, in order to check the accuracy of the new probe. This last result is not shown but agreement between the two pu match probes were found.

Ten points were measured for each one of these three distances. Five of this points above holes, and five above the reflecting surface in the slot (called here "non hole"). This way one can see if the magnitude of the impedance changes above the holes. Figures 14 and 15 shows these results for four of the ten points. In Figure 15 one can see that there are no significant differences in the impedance measured above the hole and reflecting surface. This is due to the fact that the distance from the pu probe to the perforations are relatively big, as these measurements were taken at the slot entrance. Figure 14 shows that the magnitude of the impedance is smaller just above the holes (blue and red lines). This is due to the higher particle velocity values observed near the holes, which was expected due to the physical behavior of the perforated panel.

It's not possible although, to draw conclusions about the absorption characteristics of the whole panel with measurements taken in the slot. The absorption of the panel is caused by the interactions of the holes, slots and reflecting surfaces of the panel. So, measuring in the slot just points to variations of the particle velocity near the holes and not to the overall absorption characteristics of the panel. These measurements can give valuable insight about the impedance of the hole itself.

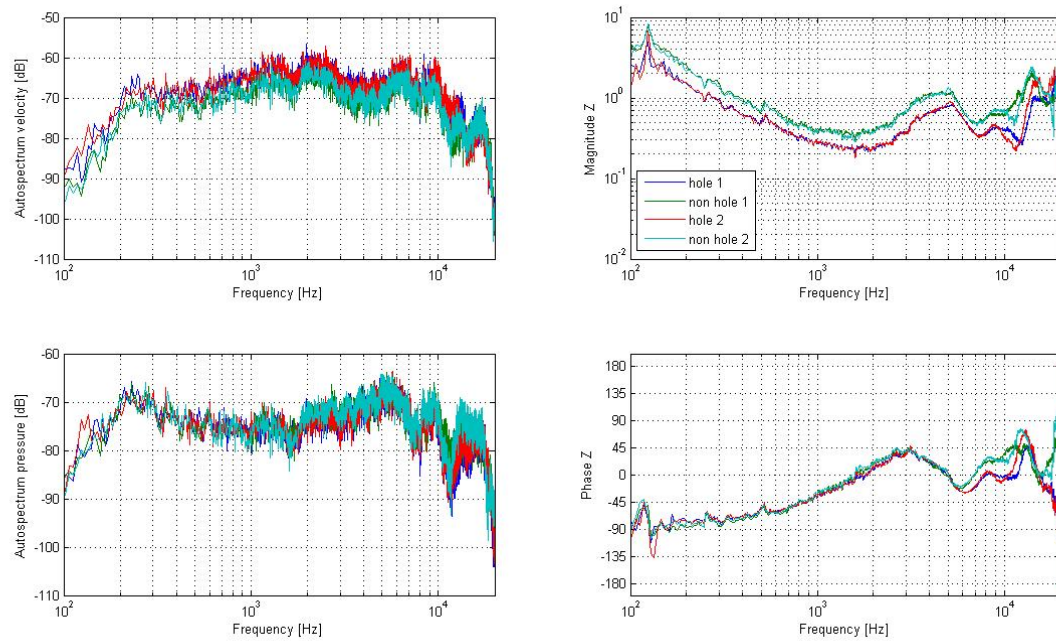


Figure 14. Acoustical surface impedance in the slot.

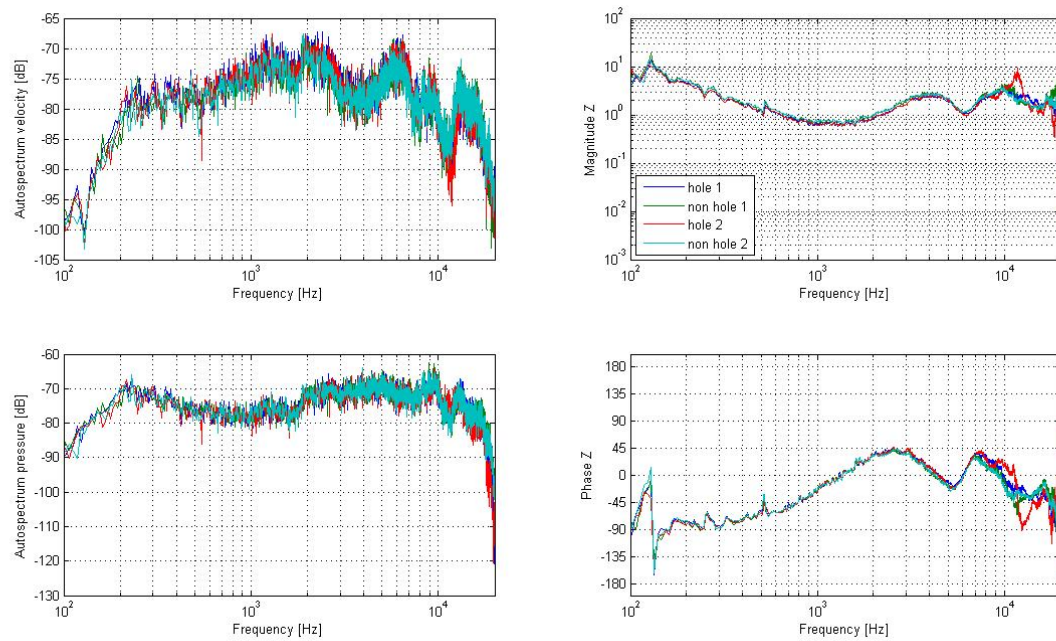


Figure 15. Acoustical surface impedance in the slot entrance.

6. Conclusions

In this paper the spatial averaged surface impedance and the reflection and absorption coefficients were measured using a pu match probe. The results show good agreement with the expected behavior of the absorber. It was also found that the value of the absorption coefficient varies over the surface of the panel and the color maps show it is bigger over the slots. These color maps also show differences between the resonant and non resonant frequencies. The surface impedance was also measured inside one slot showing that there are differences for its magnitude above the holes and reflecting surfaces inside the slot. These differences are caused mainly by changes in the value of particle velocity, as expected.

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