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ACOUSTIC ABSORBENT PANELS WITH LOW PERFORATION COEFFICIENT.

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ABSTRACT: Usually, acoustic absorbent panels consist of perforated supporting plates that act like support of absorbent materials. The perforation coefficient of the panels must be higher than 20 % for not to alter the acoustic properties of the used absorbents. At the present time, and for aesthetic reasons, perforated panels with perforation coefficients lower than 10% are preferred, which leads to a remarkable degradation of the absorption spectrum of the whole set. The present work studies the absorption spectra changes of these devices based on the acoustic characteristics of the absorbers used and on the perforation coefficients of the supporting panels.

1. INTRODUCTION

In room acoustics conditioning, the use of perforated acoustic panels is usual. They are used in ceilings and in walls, and they act as support or protection of the absorbers within the resulting device.

Perforated panels with perforation diameters of the order of several mm or even cm, and a high percentage of perforation, do not work like good absorbers, due to his low acoustic resistance, reason why they are mainly used as supporting or covering layers of the lodged acoustic materials inside them. Typically these acoustic materials are porous as mineral wools, which are those that confer to the device his absorbent acoustic performances.

Acoustic veils (non woven textiles) are also used lately. These veils can be made of a great variety of raw materials, so that they do not have the disadvantages of the fibrous materials, that can be fallen to bits with time, contaminate with small fibres the atmosphere in where it is installed, furthermore, they can be contaminated by bacteria which are very difficult to eliminate. So these alternative materials are indicated specially in sanitary enclosures, food industries and microelectronics.

When, for aesthetic reasons, the number and diameter of the perforations tend to be reduced, the effect of acoustic filter of the plate (or supporting grid) begins to arise, changing the absorption performances of the contained acoustic material within.

In this work guidelines to the most usual cases for both types of absorbers (fibrous and veils) are offered, driving the reader into the development of the electroacustic expressions necessary for the calculation of a given problem. The equivalent electroacustic circuits of these absorbent devices are defined so that getting the solution to any given situation is straightforward. The suitability of those solutions for several cases is verified in impedance tube.

Since the process of absorption in these systems is linear, the principle of separation of variables can be applied; so that the study of the acoustical characteristics of every constituent element is accomplished and then they are included into the total system.

2. ABSORPTION OF PERFORATED PANELS

To increase the absorption in the low frequency range, perforated plates are usually mounted leaving an air cavity between these and the hard backing of the enclosure. The absorption spectra of these plates will mainly depend on two parameters: the diameter of the perforations and the perforation coefficient.
A plate with a high percentage of perforation, placed in front of a rigid back, can be considered acoustically "transparent" with an absorption coefficient next to zero for all the frequencies considered. On the contrary, if the plate is perforated with a low perforation coefficient its absorption spectrum will be greater with minima located in uneven multiples of L= λ/ 2 (being L the thickness of the air cavity).
As the number of variables involved in the process is high (frequency, *f*, diameter of the perforations, *d*, thickness of the plate, *t*, perforation coefficient, *p*, and thickness of the air cavity, *L*), we will fix some of them, with typical values of commercial products. For example we will fix the diameter of the holes (˜ 6 mm), the thickness of panels (1<t<10 mm), the coefficient of perforation (p ˜ 30%), and the air cavities (5<L<30 cm).
According to the work of D. Y. Maa [1, 2], the device has a complex acoustic impedance, Z_C, corresponding to the mecano - acoustic characteristics of the perforated plate (*d, t, p*) connected in series with a reactive load corresponding to the air cavity, according to the well-known expression:

$$Z_{cavity} = -j*cotg(kL)$$

The absorption coefficient expression is:

$$\alpha(f) = \left|\frac{Z_S - 1}{Z_S + 1}\right|^2$$

where, $Z_S = Z_C + Z_{cavity}$

The following figures show plots of absorption coefficient versus frequency where the minima located at L/λ = ½ can be observed.

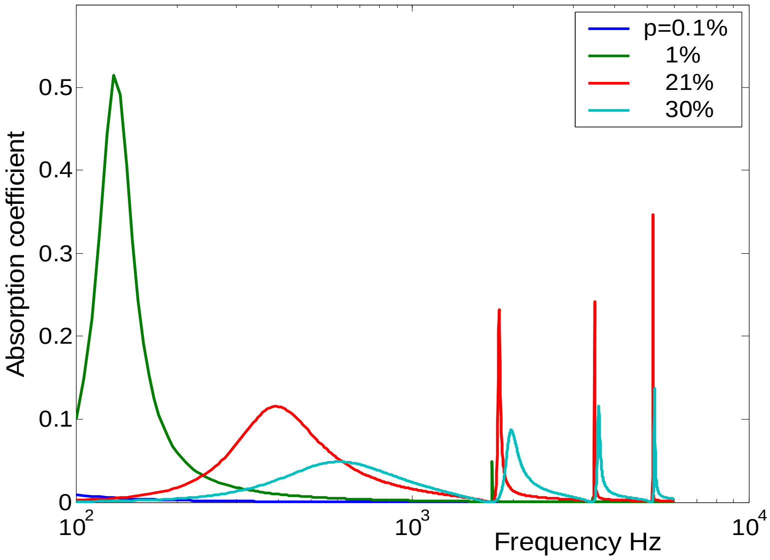

Figure 1 Absorption coefficient in function of the perforation coefficient

In figure 1 the absorption spectra of panels with a 6.5 mm diameter perforations, a 10cm air cavity and a perforation coefficient, ranging from 0.1% to 30 % are presented. It can be shown that the only absorption of the perforated plate is due to a resonator effect that happens for the different perforation percentage, and whose maximums (for a given cavity) move to higher frequencies as the perforation coefficient is increased.
If the diameter of the perforations (*6 mm*), the thickness of the plate (*11 mm*) and the perforation coefficient (*30%*) are kept constant, the absorption spectrum as a function of the thickness of the air cavity will present main maximums of absorption that diminish in amplitude and frequency as the air cavity is increased. The resonance frequency is reduced in one octave when the air cavity is doubled (fig. 7).

2.1 Characteristics of the absorbing materials used in these designs

We have seen that the perforated panels or the grids described above do not have a good absorption. That is why, normally, a layer of an absorber that usually consists of an acoustic veil or a fibrous layer (mineral wool) is backing the panel, so that the overall absorption will be increased.

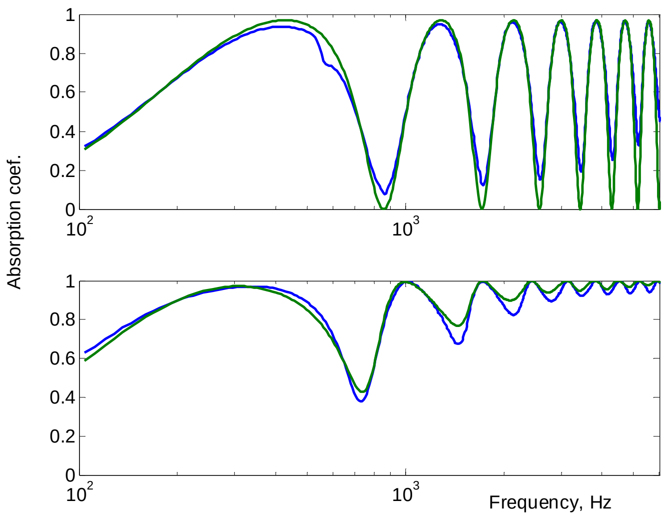

Figure 2 Acoustic absorption of a 4.5 cm layer of mineral wool (upper), and a non woven textile. Air cavity 20 cm.

For instance, in figure 2 the absorption spectra of two typical cases are presented. In the upper plot, a veil with normalized resistance to the air specific impedance (R = 1) and with an air layer of 20 cm can be seen. In the lower plot the veil is replaced by a layer of mineral wool 4,5 cm thick, and an air flow resistivity of 14000 Nsm^{-4} (the air cavity is kept constant). The green lines correspond to analytical curves and blue lines are the experimental ones. The figure shows a good correlation between measures and analytical expressions. The deeper minima for the veil are due to the lack of a reactive component in its impedance.

2.2 Combined absorbing perforated panel and layer of absorbent material

The combination of a perforated plate and an absorber is shown in figure 3. The plate is 11 mm thick, with perforations of 6.5 mm of diameter and a 23 % perforation coefficient. The upper plot has a veil as absorber and the lower one has mineral wool as backing .If figure 3 is compared with figure 2 it can be seen the low – pass filter effect of the perforated plate.
In effect, the equivalent electric circuit of the described system is made up by a resistance and a self-induction in series, for the perforated plate, plus another resistance and another self-induction in series corresponding to the characteristic impedance of the absorber, and a capacitive reactance for the air cavity between the absorber and the rigid wall. It is assumed that the absorber is in intimate contact with the perforated plate.

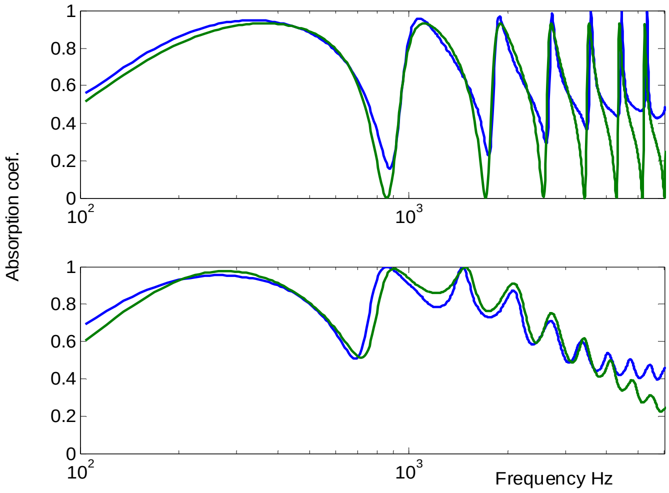

Figure 3. Absorption spectra of the combination perforated panel and absorptive material. Air cavity 20 cm.

2,3 Analysis of the acoustic performances of the combination of perforated plates with absorbent acoustic materials and air cavities.

In this section an analytical study of this kind of devices is carried out. Algorithms can be found in [1, 2] for perforated panels, in [4] for fibrous materials and in [3] for veils. Results are shown in the following figures (from figure 5 to figure 8); where it has been studied the

- Influence of the perforation coefficient of the plate. Figure 5
- Influence of the size and number of perforations (for a fixed perforation coefficient). Figure 6.
- Influence of the air cavity. Figure 7.
- Influence of the thickness of the plate. Figure 8.

In all these figures a *4.5 cm* layer of mineral wool with $\sigma=14000\ Nsm^{-4}$ has been placed behind a perforated panel of 11 mm thickness and with a 23 % perforation coefficient. Analogous figures for the case of acoustic veils would be obtained.

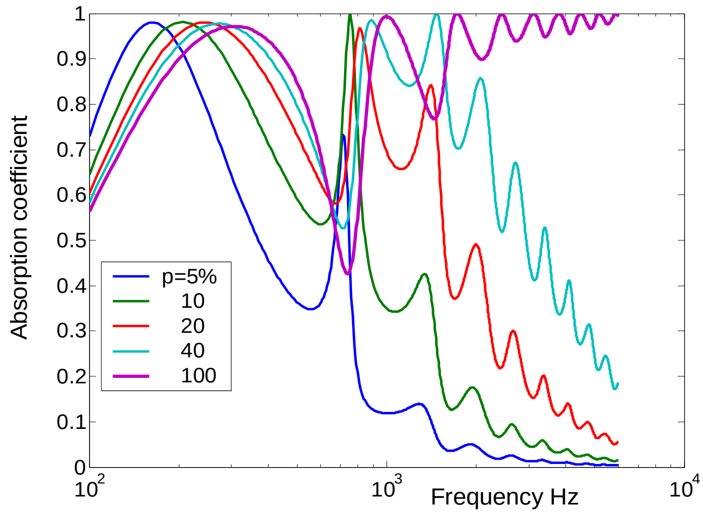

Figure 5 Absorption versus plate perforation coefficient. Panel thickness t=11 mm

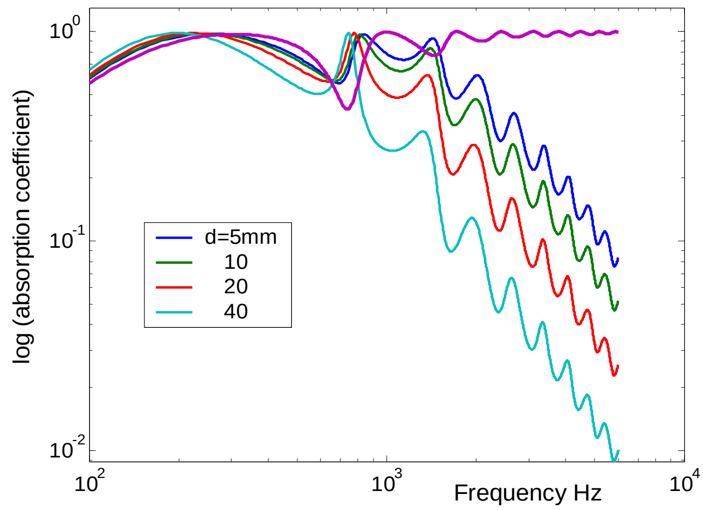

Figure 6 Absorption versus holes diameter. Perforation ratio p=23%, t=11 mm. Magenta: absorption without perforated panel

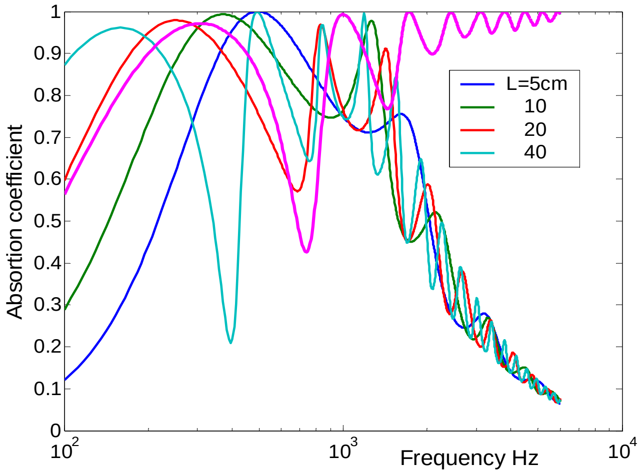

Figure 7 Absorption versus air cavity. p=23%, t=11 mm, hole diameter d=6mm

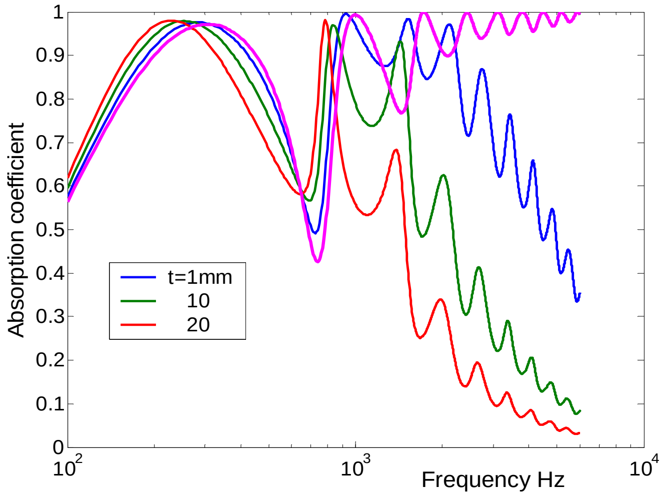

Figure 8 Absorption versus panel thickness. Perforation coefficient p=23%, Air cavity 20 cm. Magenta: absorption without perforation panel

3. DISCUSSSION.

The observation of figures 5 – 8 allows establishing the following conclusions in the use of perforated panels:

1. Very small percentage of perforation remarkably diminishes the absorption of the acoustic material backing the panel. The perforation coefficient should not ever be lower than 20 %, for maximum absorption

2. The diameter of the holes should be smaller as possible (keeping the perforation coefficient constant) with the aim to increase the absorption at high frequencies.
3. The thickness of the perforated panel should be as narrow as possible (keeping in mind the mechanical needs of the plate) so that performances at high frequencies are not damaged.
4. Increasing the rear air cavity thickness moves the absorption curve to the low frequency range. High frequencies are restricted by the low – pass filter effect inherent to the acusto – mechanical characteristics of the plate.

4. CONCLUSIONS

Throughout this work the behaviour of perforated panels has been shown by means of the use of examples.
The excellent approach between the measured experimental results in impedance tube (perpendicular incidence of plane waves to the surface of the sample) and the theoretical forecasts is verified. The formulations can be deduced easily from the suggested bibliography.
The advantage of the developed formulations consists fundamentally of its use like calculation predictive that allow "the virtual" experimentation of innumerable models that adapt to the conditions demanded in the development of the problem of raised acoustic preparation.
The chosen model as absorbent device is the one of a mineral wool layer of 4,5 cm of thickness with an air flow resistivity = 1400 Nsm^{-4}, with a perforated plate to 23% with cylindrical perforations of 6,5 mm of diameter and 11 mm of thickness. On this model it has been checked the good approach obtained by means of the algorithms developed to the effect, as well as with another alternative model in which it has been replaced the mineral wool by an acoustic veil of the same resistance as the mineral wool layer. When obtaining itself curves from absorption very similar between both models we have restricted ourselves to those of the first case.

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