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EVALUATION OF THE SOUND INSULATION OF MULTILAYER PANELS BY MEANS OF NEAR-FIELD ACOUSTIC HOLOGRAPHY

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Abstract

In this work, it is studied the acoustic and vibratory behavior of structures with the objective to evaluate its sound insulation by means of the technique of measurement without contact Near-field Acoustic Holography (NAH). This technique allows to obtain values of vibration velocity and pressure level of the multilayer panels submit to an acoustic excitation from measurements made with an array of microphones in a parallel and near plane (hologram plane) to the surface studied. It is used a box that has a window, in it the panels are placed. The box has two loudspeakers installed in the lateral ones with which broadband noise is generated in its interior. By the outer part of the box, the sound pressure in the hologram plane is measured. With these values and backpropagating the sound field, the sound pressure in the surface of the multilayer panels is obtained. The vibratory behavior of the different materials that form the multilayer panels is evaluated. The values of transmission loss obtained by means of NAH are compared with values facilitated by the Aisla 3.0 programme, that calculates the transmission loss according to the prediction model of the acoustic behavior of multilayer structures of Ookura&Saito. The transmission loss obtained from NAH and the transmission loss obtained by means of the prediction model of Ookura&Saito present acceptable similar results.

INTRODUCTION

The object of this work is the study of the relative sound insulation of multilayer panels, using as tool the technique "Near-field Acoustic Holography”. In the validation of the theories on the acoustic isolation is necessary to evaluate different materials and configurations. The objective is to increase to the maximum the isolation index of a certain configuration, trying to diminish the costs as much as possible. The study of the acoustic behavior of different configurations is usually carried out in transmission camera. The results of the measurements under these conditions don't normally coincide with measurements "in situ" [1], since the assembly conditions are uncontrollable. It is not sometimes necessary to obtain absolute results but it is enough with knowing if a device isolates more than other (Prototypes). Different models and theories and techniques of measurement that predict the acoustic behavior of structures are developed in diverse works, for their application in acoustic isolation, from models and theories to characterize absorbent materials until methods of characterization of absorbent materials measured in the tube of Kundt [2], [3]. The results of a simulation are for ideal partitions with elastic properties that don't vary in function of the angle of incidence. In many of the materials usually used in the construction, such as wooden panels, conglomerate, brick or glass cannot even make sure isotropy, for what the elastic properties or the density of the material can vary in function of the angle of incidence. The assembly characteristics influence a lot in model's type to take to make the prediction. In these circumstances it is necessary the use of techniques of measurement “in situ” that they facilitate the obtaining of the acoustic isolation “in situ”. In this work, the NAH technique is used. It is based in the recording the sound pressure by means of an array of microphones in a parallel and near plane to the multilayer panels, excited acoustically on the other side. Known these values at certain distance and by means of techniques of digital processed, it is possible to obtain the acoustic magnitudes in the surface study object by means of the back-propagation of the acoustic field. Their great utility is due to that starting from values registered in a two dimension surface denominated hologram plane, it can reconstruct the sound field in any other plane.

FOUNDATIONS

The NAH technique arose in 1980 of hands of Williams and Maynard like an improved solution of the Conventional Acoustic Holography (1960), since thanks to the measurements in near field the evanescent waves are captured (subsonic waves that decay exponentially with the distance to the source) created by the sound source, and that they contain details of high resolution about this source [4-12]. This technique has been used in different applications like in localization of sound sources, for example sources radiating or plates vibrating [13-15], in the surface of motors [16,17], in vehicles [18] or to study the radiation of radiant structures [19,20].

Starting from Green's theorem, it can be derived an integral one that describes the acoustic pressure in any place of the half space between the source and a measure plane.

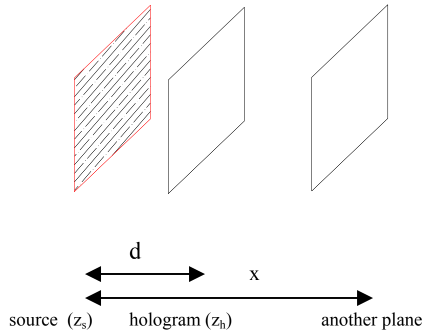

Figure 1 - Three measure planes, source plane, hologram plane and parallel distant plane to the source.

Using the equation (1), the complex pressure in any point in the free space can be expressed like a function of the complex pressure $(\overline{p})$ in the plane of the source z_s.

$$\overline{p}(x,y,z) = -\int_{-\infty}^{\infty}\int \overline{p}_s(x',y',z_s)\times\overline{G}'(x-x',y-y',z-z_s)dx'dy' \tag{1}$$

where $\overline{p}_s(x',y',z_s)$ is the distribution of complex pressure in z_s and $\overline{G}'(x-x',y-y',z-z_s)$ is the one derived normal of the Green's function that satisfies the Dirichlet homogeneous limit condition in z_s. If it is considered that all the points are located in the measurement plane $\overline{p}_h(x,y,z_h)$, denominated hologram, z_h, then $z_h - z_s$ is a constant, the equation (1) describes a convolution in two dimensions between the complex pressure in the plane z_s and the modified Green's function. The convolution in the real space becomes a simple product in the space of the wave number. Taking the Fourier Transform in both faces of the equation (1) the distribution of complex pressure in hologram plane is obtained like product in the space of wave number:

$$\overline{p}_h(k_x,k_y,z_h) = \overline{p}_s(k_x,k_y,z_s)\cdot\overline{G}'(k_x,k_y,z_h-z_s) \tag{2}$$

Known the pressure in the hologram plane, one can obtain the pressure in the plane of the surface of the source:

$$\overline{p}_s(k_x,k_y,z_s) = \overline{p}_h(k_x,k_y,z_h)\cdot\overline{G}'^{-1}(k_x,k_y,d) \tag{3}$$

where $d = z_h - z_s$ is defines as the distance between the reconstructed plane of the sound source and the hologram plane, and $\overline{G}'^{-1}$ is the inverse propagator. The Fourier Transform of modified Green's function defined as propagator is expressed according to (4):

$$\overline{G}'\left(k_x,k_y,d\right)=\begin{cases} e^{id\sqrt{k^2-k_x^2-k_y^2}} & para \quad k_x^2+k_y^2 \le k^2\ ; \quad c_x,c_y > c\ ; \quad k_z\ real \qquad (a) \\ e^{-d\sqrt{k_x^2+k_y^2-k^2}} & para \quad k_x^2+k_y^2 > k^2\ ; \quad c_x\ o\ c_y < c\ ; \quad k_z\ imaginario \quad (b) \end{cases} \tag{4}$$

With the pressure in the k space, $\overline{p}(k_x, k_y, z_h)$**,** can be determined the particle velocity applying the equation of Euler and taking their Inverse Fourier Transform of the equation obtaining:

$$\overline{v}(k_x, k_y, z) = \frac{1}{\omega\rho}\left(k_x e_x + k_y e_y - ie_z \frac{\partial}{\partial z}\right)\overline{p}(k_x, k_y, d) \tag{5}$$

In a stationary sound field it is possible to measure the sound pressure with an only microphone using a reference sign. There are errors due to measurement positions. As any inverse method, the problem linked to the amplification of the evanescent waves in the spectrum of wave number can be increased with the leakage (or low sampling) due to the truncation of the sound field for the array of finite size. In this work, the filter Wiener is used [21].

DEVELOPMENT

It is studied the pressure level and the vibration velocity in the external surface of the multilayer structures, mounted in the window of the camera, figure 2. The box has installed two speakers in its lateral ones. As the pressure level inside the box is known, the relative transmission loss of these configurations can be evaluated. The experimental device presents limitations and the weak part, acoustically speaking, it is the window, however to carry out comparative between different structures the device offers satisfactory results. The materials used to study the multilayer configurations were measured with NAH in an individual way and as a whole. Panels of wooden fiber of 5mm and 3 mm, wool of polyester of 2.5 cm and steel of 1 mm were analyzed, figure 3. It is carried out 1064 measurements with a lineal array of 4 microphones, 28x38 measurements, to a distance of 2 cm of the window of the box where the materials were placed, with a distance among microphones of 1.5 cm in axes x and y. By means of a program based on the reconstruction of NAH, the average values of pressure level and vibration velocity were calculated in the surface from the external material to the window. In the filter Wiener, the parameters kc = 0.6kmax and α=0.2 were used. Some of the obtained values of pressure level and vibration velocity in function of the frequency are represented in the figures 4 and 5. In general, in figure 4, it is observed that when adding layers the pressure level measured in the exterior of the multilayer panels diminishes. The effect of the wool is appreciated to high frequency. It is observed that the "wood layer 5mm" present a pressure level higher than the configuration "wood 5mm+steel" and that the multilayer structure "wood 5mm+wool+steel" starting from 1 kHz. In figure 5, the vibration velocity is represented for one, two and three layers, with wood, wool and steel. It is observed a similar behavior with the pressure level. Starting from 1 kHz, the wood presents a vibration velocity higher than the configuration of two layers and this bigger than that of three layers. It is proved that the wool contributes with its absorption in high frequency.

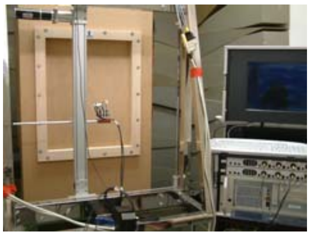

Figure 2. Configuration of measurement

Figure 3. Materials used.

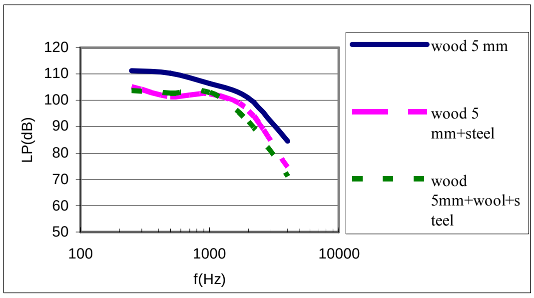

Figure 4. Pressure Level (dB) of layers and multilayer of wood 5 mm , wool and steel 1mm

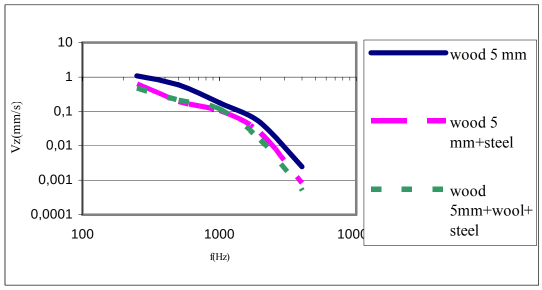

Figure 5. Vibration velocity (mm/s) in the surface of the external material of layers and multilayer of wood 5 mm, wool and steel 1mm.

The Transmission Loss (TL) of inside of the box to the exterior can be calculated by means of the equation (6) [22]. L_S it is the pressure level in the area of the source, that is to say, inside the box, L_R is the pressure level in the receiver area, that is to say, in the surface of the material, and t_R is the average reverberation time of the room, of 500 Hz to 4 kHz, that is of 0.6 s in the considered range of frequencies. It is carried out an average of fifteen measurements with microphone inside the box to evaluate L_S. The Transmission Loss of the simple layers were calculated using the equation (6) where the receiver pressure level was obtained of the calculation of pressure level obtained with NAH.

$$\left(L_S - L_R\right) = TL - 10\log\frac{t_r}{0{,}5} \tag{6}$$

However to calculate the TL of the multilayer structure, it is used the vibration velocity of the external layer obtained with NAH, to assure that the lateral transmissions don't influence in the total response of the multilayer structure, starting from this the pressure was calculated in the external layer as:

$$P = v\rho_0 c \tag{7}$$

This TL was obtained according to the expression 8. In this case it is not considered the factor of the logarithm of the equation (6) because the vibration velocity is less influenced by the absorption of the room.

$$TL = (L_S - L_R) \tag{8}$$

In figure 6, one can observe that the Transmission Loss of the multilayer structures present high values in the whole range of frequencies regarding the individual materials (wood 5mm and steel). It is also observed that the difference between "wood 5mm+wool+steel" and "wood 5mm+steel" is only observed in the range where the wool absorbs, that is in high frequency, where three layers present a bigger isolation that two layers. Regarding the TL of the individual materials it is observed that the TL of the steel is about 5 dB bigger that the TL of the wood 5mm.

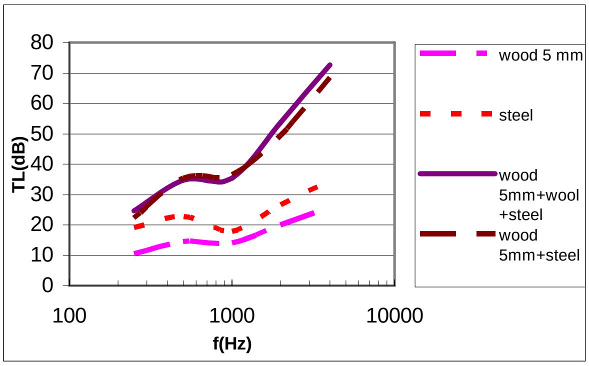

Figure 6. TL(dB) of wood 5mm, steel and multilayer of them + wool.

To validate the results obtained with NAH, it is used the software Aisla 3.0 [23] that calculates the Transmission Loss according to the prediction model of Ookura&Saito [24], figure 7. In this case, it is only necessary to select the materials and the absorbent material of the multilayer structure. Selecting a material and knowing their thickness, the program of its database shows the critical frequency, the surface density and the loss factor. Regarding the absorbent, it shows the flow resistance in function of their thickness. The data of each material are specified in table 1. In table 2, it is represented the coefficient of absorption of the polyester wool used. In the figure 8, it is represented the Transmission Loss of the multilayer panels "wood 5mm+wool+steel" calculated with the software Aisla 3.0 and with the technique NAH. The NAH technique and the Ookura&Saito model present similar results, being observed bigger difference among them to low frequency.

	Steel	Wood	
Thickness (mm)	1	5	3
Surface density (kg/m2)	11,4	3,8	2,3
Critical frequency (Hz)	1044,6	1000,4	1667,3
Loss factor	0,021	0,024	0,024

Table 1. Data of materials used

f(Hz)	α
250	0.4
500	0.4
1000	0.8
2000	0.8
4000	0.8

Table 2. Coefficient of absorption of the polyester wool

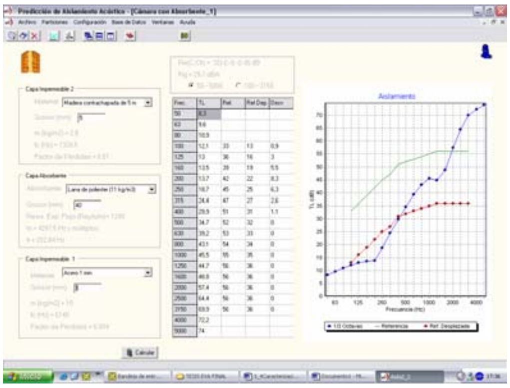

Figure 7 Software Aisla 2.2.

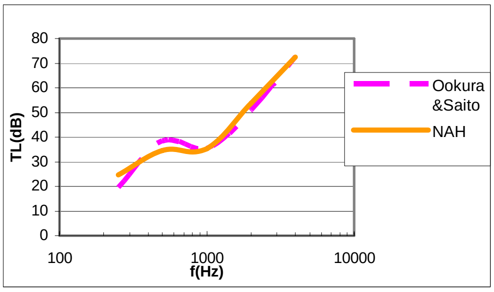

Figure 8. Comparative of the model Ookura&Saito and the technique NAH to obtain the TL of the configuration "wood 5mm+wool+steel"

CONCLUSIONS

The technique NAH is beneficial in the experimental study of the acoustic and vibratory behavior of multilayer panels, It is possible to evaluate the relative Transmission Loss of different configurations by means of the values obtained with NAH and with the measure device used (Prototype). Although the device presents limitations, it offers satisfactory results to carry out comparative of Transmission Loss between different multilayer panels. It is convenient to use this system like complementary or as an intermediate step to the measurement "in situ" or in laboratory. The results of Transmision Loss obtained with NAH and with the model of prediction of Ookura&Saito offer acceptable similar results.

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