Can we hear the complexity of vibrating plates ?

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Introduction

This paper presents a psychomechanic investigation which is a combination of vibroacoustic and psychoacoustic studies. One of the aims of psychomechanics is to extract perceptual attributes which are relevant for the auditory perception of sounds radiated by vibrating structures. Up to now, the geometric forms examined are mainly bars [1] and plates [2], [3]. In this paper, we study the case of a fluid-loaded plate, clamped and excited by a transient point force. In order to reduce the complexity of the vibroacoustic model, two investigations were undertaken. Firstly, we wanted to know if a plate with variable thickness can be modeled by a constant-thickness one that would be equivalent, from a perceptual point of view. Dissimilarity tests were run on synthesized sounds for both types of plates. Pitch of sounds was the perceptual attribute used by the listeners and allowed us to define an equivalent thickness. A second investigation consists in comparing synthesized and recorded sounds of constant-thickness plates. Sounds of a hammer striking a plate were recorded in an anechoïc chamber and compared with synthesized sounds via a "sensory" time-frequency representation.

Comparison of sounds radiated by variable and constant thickness plates

In order to simplify a vibroacoustic model, we wished to know if it was possible to replace a plate with variable thickness by an equivalent constant one, from an auditory perception point of view.

Characteristics of sounds

The plate is rectangular, thin, baffled, elastic, clamped and it is excited by a transient point force the duration of which is 10^{-5} ms. It is assumed to be surrounded by air. The method of resonance modes is used to calculate the radiated acoustic field. Theoretical details can be found in an ealier paper [4]. The dimension of the plate is 35×50 cm. The thickness h of the plate is either constant or variable. In the latter case, it is written as: $h(x,y) = h_0(1+f(x,y))$ where $h_0 = 5$ mm, and $f(x,y)$ is a fonction which depends on the geometry of the plate. Four geometries of variable-thickness plates were tested. Figure 1 presents an example of such geometry. Signals were synthesized with a sampling frequency of 44100 Hz. To reduce the calculation time, the sounds were computed for a duration of 2s and with 70 modes (that is for frequencies up to 8000 Hz). The first resonance frequency is around 270 Hz. Sounds were normalized in order to have the same overall loudness.

The resonance frequencies of the plate, which are the different components of the sound spectrum, are linked to thickness. Thereby, a variation of 20% of the plate thickness implies a variation of 20% of the resonance frequencies.

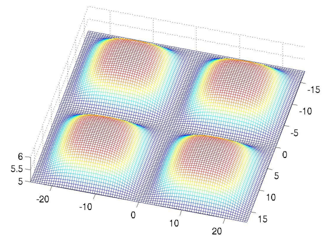

Figure 1: Geometry of a variable-thickness plate

Procedure

Six series of hearing tests of dissimilarity were run in an isolated sound-proof room. A method of paired comparison was used to evaluate the dissimilarity between one sound of variable-thickness plate and N other sounds of different constant-thickness plates. Sounds were presented in pairs in random order. After each presentation, the subjects were asked to evaluate how similar or dissimilar the signals of the pair were, and then to quantify their jugement by locating a cursor on a line displayed on a screen. The two end points of the line were labelled very similar and very dissimilar and assigned the values of 0 and 6 respectively. Sixteen normal hearing listeners took part in the experiments. They were students or members of the laboratory.

Results

Six experiments were undertaken for the four geometries and two different locations of impact. Two representative results among the six are presented. Figure 2 and 3 present the evaluated dissimilarities versus the thickness of N plates with constant thickness. Figure 2, presents an interesting shape that we found for one plate; we will call it case #1. The minimum of dissimilarity, in this case, corresponds to the coincidence of the first partial of the spectrum. The first resonance frequency of the variable thickness plate coincides with the first resonance frequency of the 5.24 mm plate. Figure 3 presents another typical shape, that we call case #2, which displays a global minimum and a local minimum of dissimilarity. The local minimum, at 5.1 mm, corresponds to the coincidence of the first partial of the spectrum as described before. The global minimum, at 5.2 mm, seems to be related to pitch similarity between sounds.

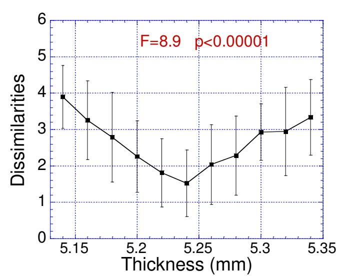

Figure 2: Dissimilarities versus constant thickness of plates

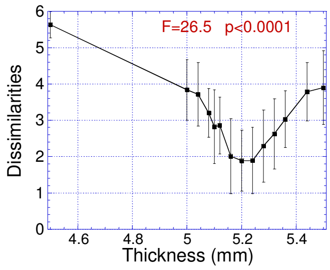

Figure 3: Dissimilarities versus constant thickness of plates

Discussion

Sounds are generally heard as similar when their first resonance frequency coincide. But in some cases, they can also be similar because of another spectral criterion. This particular criterion has not been clearly identified yet. It also happens that no equivalent constant-thickness plate can be found to some non-constant plates. Why is the similarity criterion either the first resonance frequency or another attribute? Equation (1) presents the expression of $(\Delta f/f)_{av}$:

$$\left(\frac{\Delta f}{f}\right)_{av} = \frac{1}{70}\sum_{k=1}^{70}\left|\left(\frac{\Delta f_k}{f_k}\right) - \left(\frac{\Delta f_{k-1}}{f_{k-1}}\right)\right| \qquad (1)$$

f_k is the k^{th} resonance frequency of the plate i.e. the k^{th} partial of the spectrum of the sound. $\Delta f/f$ represents the relative deviation of the k^{th} resonance frequency of the constant-thickness plate to the k^{th} of the variable one. $(\Delta f/f)_{av}$ is the average of the 70 deviations. Consequently, if the $(\Delta f/f)_{av}$ is large, it implies a different spectral envelope.

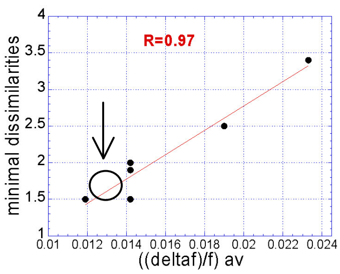

Figure 4: Minimal dissimilarities versus $(\Delta f/f)_{av}$

Figure 4 presents minimal dissimilarities (or global minimum), for the six results of hearing tests, versus $(\Delta f/f)_{av}$. For case #1 (figure 2), at $(\Delta f/f)_{av}$ = 0.012, the first resonance frequency is the physical parameter which is linked to the pitch. However, if $(\Delta f/f)_{av}$ is larger than a critical value in the circle in figure 4, as case #2 (figure 3), there is another physical parameter which is linked to the pitch. If the $(\Delta f/f)_{av}$ is larger than 0.021, no equivalent sound of constant thickness plate can be found.

Comparative analysis of recorded and synthesized sounds of plates

Preliminary vibroacoustic experiments have been undertaken on recorded and synthesized sounds of rectangular plates [5]. Signals were studied for a duration of 100 ms. The present study is a continuation of [5], and 2s of the sound are taken into account. The studied plate is thin, elastic, clamped and excited by an impact hammer with a rubber head. The dimensions of the plate are 89.4×75.4×0.2 cm. A sound was recorded in an anechoïc chamber and a synthesis of that sound was done by using the method of resonance modes. The sounds were computed with 200 modes (that is for frequencies up to 2000 Hz). The first resonance frequency is 26 Hz. Synthesized and recorded sounds were normalized. Their "sensory" time-frequency representations are presented in figure 5. The two diagrams shows the specific loudness as a function of time, over the first ten Bark bands where all the energy is found. The diagrams are very similar in the time course of their specific-loudness functions. Nevertheless, loudness fluctations seems to be slightly different.

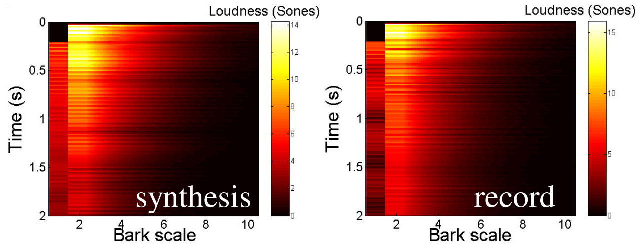

Figure 5: "Sensory" time-frequency representations

Conclusion

The aim of these two studies is to know if it is possible to reduce the complexity of vibroacoustic models of plate. First, it has been shown that a sound of a constant-thickness plate can be similar to a sound of a plate with variable thickness. An equivalent thickness was deduced and the perceptual attribute of similarity seems to be the pitch defined either by the coincidence of the first resonance frequency or by another criterion that still remains to be identified precisely. Thus, we will run an experiment of pitch matching between a sound of plate and a pure tone. This test will allow us to deduce the spectral component which is responsible for pitch perception. Afterwards, similarity tests will be run between synthesized and recorded sounds of plate. Later, in order to reduce computation time, we wish to simplify the model provided that perception is realistic.

References

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