Perception of Sounds Radiated From a Vibrating Plate: Comparison of Structural Parameters Influences

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Introduction

Building structures act as filters that modify spectral components of sounds they transmit. Their structural parameters values can then be set to design environmental sounds in order to improve comfort inside building. Our work aims to complete knowledge on the physical behavior of structures with a qualitative evaluation of sounds they transmit by assessing with precision the effects of structural parameters on sound perception.

This paper presents a synthesis of the effects of a glass plate structural parameters variation on sound perception and proposes a solution to classify these parameters in order of their importance from a perceptual point of view.

Method

Stimuli Synthesis

From the physical model of a thin glass plate excited by a pink noise, the radiated sound is simulated at two points corresponding to the ears position of a human being which stands up in front of the structure. For each studied parameter, several stimuli corresponding to several values of the studied parameter are simulated and are submitted to a panel of subjects for a sound perception test. This paper presents the study for three parameters: the structural damping η_s, the thickness h and the stiffness at viscoelastic boundary conditions (BC) of the plate.

Sound perception tests

For each one of the three studied parameters, the corresponding stimuli are submitted by pairs to a sound perception test. Sounds are restituted in a quiet room with an open headphone. For a panel of 20 subjects, the judgment task consists in the evaluation of the dissimilarity on a seven-point scale and of the preference by dichotomous choice.

Dissimilarities are scaled with the Indscal M.D.S. algorithm in order to plot the perceptual space [1]. The dominance judgments on the preference are transformed into preference scores according to the law of comparative judgment [4].

Results

The coupling of the physical analysis of the plate responses and of the sound perception tests analysis has led to the results detailed in this section.

The scaling of dissimilarities corresponding to the structural damping variation has led to a single dimension perceptual space. As shown on figure 1, the structural damping variation is explained by the loudness of sounds (r=0.996, p<0.001). The preference scores analysis leads to the same conclusions [2].

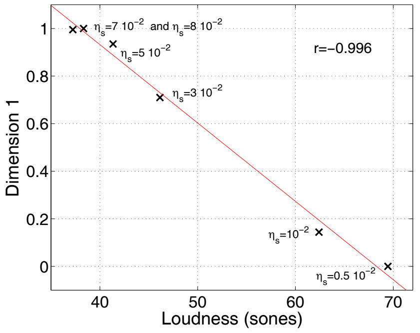

Figure 1: Effect of structural damping variation. Dimension 1 of the perceptual space versus Zwicker's loudness.

For the thickness variation, the corresponding perceptual space is also monodimensional. As shown on figure 2, the thickness variation is explained by the Log(N.F.D.) metrics (r=0.994, p<0.001). The latter quantifies the mean position of resonant frequencies along the frequency axis and is highly correlated with the first mode frequency [2]. In its logarithmic form, this metrics can be interpreted with a good approximation as the pitch of sounds. Subjects have then used the frequency content of sounds to differentiate stimuli. The preference scores analysis has led to the same conclusions.

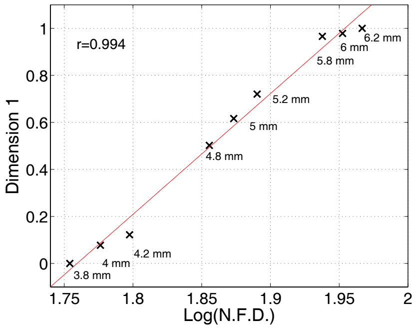

Figure 2: Effect of thickness variation. Dimension 1 of the perceptual space versus Log(N.F.D.) values.

The third result concerns the effect of stiffness variation at viscoelastic BC of the plate. Translational stiffness has been increased in order to simulate various BC of the plate from classical free to simply supported BC. Then, the rotational stiffness has been increased to simulate different BC of the plate from simply supported to clamped BC. Two stimuli with mixed BC, i.e. variation of both the translational and the rotational stiffnesses, have been added to the test. The perceptual space corresponding to the BC stiffness variation has two dimensions. The first dimension is explained by the Zwicker's loudness of sounds ($r=0.973$, $p<0.001$) and the second one is explained by the variation of their frequency content ($r=-0.953$, $p<0.001$) quantified by the log(N.F.D.) metrics [2].

Classification of the structural parameters

The three results presented previously have explained with precision the effect of each one of the three structural parameters on sound perception. Despite of this interest, the drawback of the proposed method is that it does not allow results to be given about the classification of structural parameters in their order of importance on sound perception.

Nevertheless, one can observe in the results presented previously that only two metrics have been used to explained the dimensions of the perceptual spaces: the Zwicker's loudness and the log(N.F.D.) metrics. These two metrics are absolute values and then directly comparable between them. The figure 3 presents a perceptual space reconstituted from the Zwicker's loudness and Log(N.F.D.) values. The comparison of the three tested parameters in this space shows that the three studied parameters can be classified in the following order: the glass structural damping variation between 0.5×10^{-2} and 8×10^{-2} seems to be the most influent parameter followed by the stiffness variation at viscoelastic BC of the plate. These two latter seem to be more influent than the plate thickness variation between 3.8 mm and 6.2 mm. These results are in agreement with a study led by Hamzaoui *et al.* [3] which have used an experimental design method.

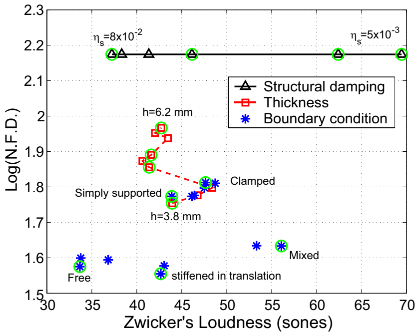

Figure 3: Reconstituted perceptual space.

This reconstituted perceptual space has been experimentally verified by an only sound perception test grouping all structural parameters variations (selected stimuli are highlighted by a red ring on figure 3). The perceptual space corresponding to this new test is plotted on figure 4. One can retrieve the two metrics, Zwicker's loudness ($r=-0.877$, $p<0.001$) and log(N.F.D.) ($r=0.912$, $p<0.001$), correlated with the coordinates of sounds along the two dimensions of this space. Moreover, the overall conclusions about the importance of structural parameters effects on sound perception are respected. Nevertheless and as it has already been mentioned, this last solution gives less precise results than the chosen solution that consists in studying the influence of independent variations of structural parameters on sound perception.

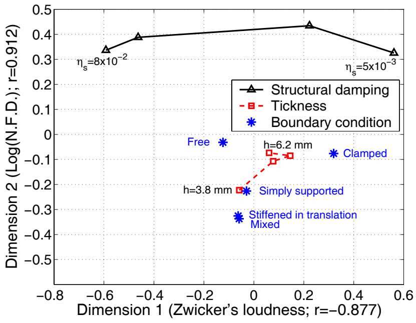

Figure 4: Perceptual space for simultaneous variation of the three structural parameters

Conclusions

This paper shows the advantages of using a method which consists in studying the influence of independent variations of a plate structural parameters on sound perception. This approach allows to obtain a reliable and accurate information on the relationship between the structural parameter variation and the sensation it produces. Furthermore, its main drawback has been by-passed by proposing a solution to classify the structural parameters versus the importance order of their effects on sound perception.

References

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