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Technical note

Piano soundboard: structural behavior, numerical and experimental study in the modal range

J. Berthaut*, M.N. Ichchou, L. Jézéquel

Laboratoire de Tribologie et Dynamique des Systèmes, Ecole Centrale de Lyon, Bat. E6, 69134 Ecully, France

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Abstract

The low frequency broadband vibrational behavior of a piano soundboard is considered. Attention is focused on the ability of finite element models and analytical models to predict precisely the behavior of such a complicated structure—especially with its orthotropy and rib effects. In order to validate these abilities, an experimental modal analysis, considered as the reference, is compared first with a numerical calculation and then with an analytical modeling of the modal basis of the same soundboard. The high structural complexity of the soundboard exceeds the analytical capabilities, but agreement is very good for the numerical model, in the frequency domain, and equally in the spatial one. The final aim is to generate a numerical tool for designing and optimizing piano soundboards.

Keywords: Piano soundboard; Modal analysis; Finite elements model; Orthotropy; Shell vibrational properties; Homogenization
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1. Introduction

XIXth century and early XXth century piano manufacturers were interested in many improvements in piano design. But innovation in this sector gradually vanished and lately seems rather poor. This fact is essentially due to the high cost of

* Corresponding author.
E-mail address: berthaut@mecasola.ec-lyon.fr (J. Berthaut).

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developing a new product *blindly*, for very hard-to-please customers. That is why piano makers need tools predicting the behavior of potentially modified products, without having to build them. This goal is quite complicated since Grand Pianos have many complex details that are determinant for their acoustic performance [2].

Relatively few experiments [5,6,11] have been conducted concerning the vibrational behavior of the piano acoustic radiator, i.e. the soundboard, which is essential to understand what a numerical tool needs to predict. Giordano [4] proposed a simple model that takes into account orthotropy and ribs separately: he used a finite differences scheme to calculate a collocalized mechanical impedance of a square clamped board. This work showed that orthotropy and ribs, even approximately described, are necessary to fit with experimental behavior—especially the mean value and the frequency dependence of the mechanical impedance. His aim was to generate an approximate model that could predict global behavior, without taking into account the geometrical modeling and deformed shape of the structure. In an opposite approach, Kindel and Chih Wang [8] used a finite element model to describe the dynamics of a standard soundboard. Rib effects were put into orthotropy parameters, and attention was payed to the boundary conditions. The comparison was made only visually off the mode shapes. The aim of the present work is to form both a precise numerical model (comprising technical geometric features and each rib individually) and an analytical model (where ribs are *melted* into material properties) of a specific soundboard, and to precisely compare the results with a complete modal analysis so these modelings may be validated. The main improvements are the number of modes analyzed (about 21), the comparison tools that permit geometrical and frequency validations, and the analytical modeling (homogenization) tested.

This paper describes the construction of the modal basis of a particular soundboard using three methods. In the first part, it is constructed by processing experimental data provided by broadband measurements. In the second part, a quite precise numerical calculation provides the modes. The third part develops an analytical modeling where the ribs are taken into acount by modifying the material properties of the wood. The last part presents the results and compares them, in both the spectral domain and the spatial one. Finally, the conclusion is that the precise numerical modeling is very acurate for the modal description of the piano soundboard, but all the technical geometric features of the ribs must be taken into account (the analytical model fails).

2. Experimental study

2.1. Setup

The experiments were made on a Pleyel P190 model[1], lightly supported by a very flexible support. This mounting makes it possible to consider the boundary condi-

[1] Provided courtesy of the *Manufacture Francaise de pianos,* Croupillac, 30319 ALES Cedex.