# ASPECTS REGARDING DYNAMIC BEHAVIOUR OF LIGNO-CELLULOSE PLATES WITH DIFFERENT STRUTTING SYSTEMS

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**Abstract:** The paper presents the experimental results concerning the dynamical behavior of ligno-cellulose composite plates with different stiffening braces. Two types of tests were performed: non-contact test (with acoustic excitation) and contact method (with mechanical vibrations of mini-shaker). Within the first part of the paper, the methods and the types of the studied plates are depicted. Within the second part, the results of the experimental research studies namely the modal shapes (Fig. 1. Chladni pattern), the Fourier analysis and the power spectrum density are presented. The identification of dynamic behavior of each type of plate aims the optimization of stiffening structure of plates in accordance with the desired resonance frequencies.

**Keywords**: ligno-cellulose composite, dynamic behavior, Chladni pattern, resonance frequency

## 1. INTRODUCTION

The acoustic qualities of a mechanical structure are intrinsically linked to the material they are made of and also linked to elastically properties. The acoustical characteristics of the wooden material from the plates' structures are influenced on the one hand by the elasticity of the material along and perpendicular to the fibres, under cross and longitudinal vibrations and on the other hand depend on the internal friction

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phenomena, caused by the energy of the dissipated vibration.

The structure of classical guitar is made up of three subassemblies: the acoustic box, the neck and the strings which are composed by many others elements. The acoustic box amplifies the musical sounds and it is made up of the top plate, back plate and the sides (Fig. 1). These elements are of solid wood or/and of ligno-cellulose composite materials with mechanical, elastic and acoustical properties optimal for static and cyclic stresses specific to musical instruments.

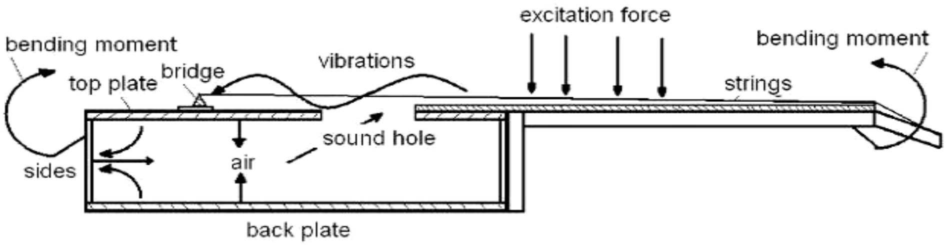



**Fig. 1.** The mechanical structure of the guitar

The guitar's acoustical quality is determined by numerous factors, such as: the plates' geometry and structure, the quality of the materials and their physical, elastic, mechanical and acoustical characteristics, the surfaces' quality and the finishing, the strings' quality and the musician's skillfulness etc.

The paper focuses on the influence of mass and stiffness of plates as constituents of the guitars as a decisive factor in the quality of the dynamical response of the entire structure - the guitar. The variation of mass and stiffness of soundboard depend on the number, materials and pattern of strutting system applied on plates. There are numerous ways of top braces positioning and number on the acoustic plates, some of them studied and standardized and some others now being researched and investigated. Many theoretical and experimental studies on different types of guitars were investigated from numerous points of view: physical, psycho-acoustical, mechanical, mathematical, musical, and the problems are still open.

Due to the complexity of the phenomena of stringed instruments, each researcher dealt with the aspects which he considered relevant to him. Some of them, like Elejabarrieta, Ezcurra and Santamaria (2004, 2007), performed the modal analysis and the vibration behaviour on the classical guitar in its different construction stages using FEM. Others – Bernard Richardson, Howard Wright with some colleagues from Cardiff University and Ra Inta from University of New South Wales – tried to establish the influence of the individual components, monitoring the quantitative and qualitative contributions. Paul M. Shaheen (2004) focused on the sensitivity analyses of the folk guitar simulating the building process. Serghei Vladimirovici (2006) researched the influence of the Russian strutting system on the dynamic behaviour of the plates and managed to improve the quality of the sound of the guitar according to the design and the dimensions of the fan bracing. For Becache, Chaigne, Derveaux and Joly (2004) the simulation coupling between the inner fluid and the structure represented one of the theoretical studies. Stanciu, Curtu, Itu (2008) focused on the modelling of the different types of classical guitar manufactured in their country and on analysing the dynamic behaviour of the plates as free structures and as parts of the guitar body. Bader (2005) brought into focus the physical sounds of the instruments from a musicological point of view. He approached the difference between continual and discrete mechanics, elaborating an interesting theory about impedance of second order to solve the problem of overtones (Stanciu, 2008), (Curtu, 2008).

## 2. MATERIALS AND METHODS

In the case of the undertaken researches were studied 5 types of plates which were freely supported on spring foam support. The material of plates was resonance spruce.

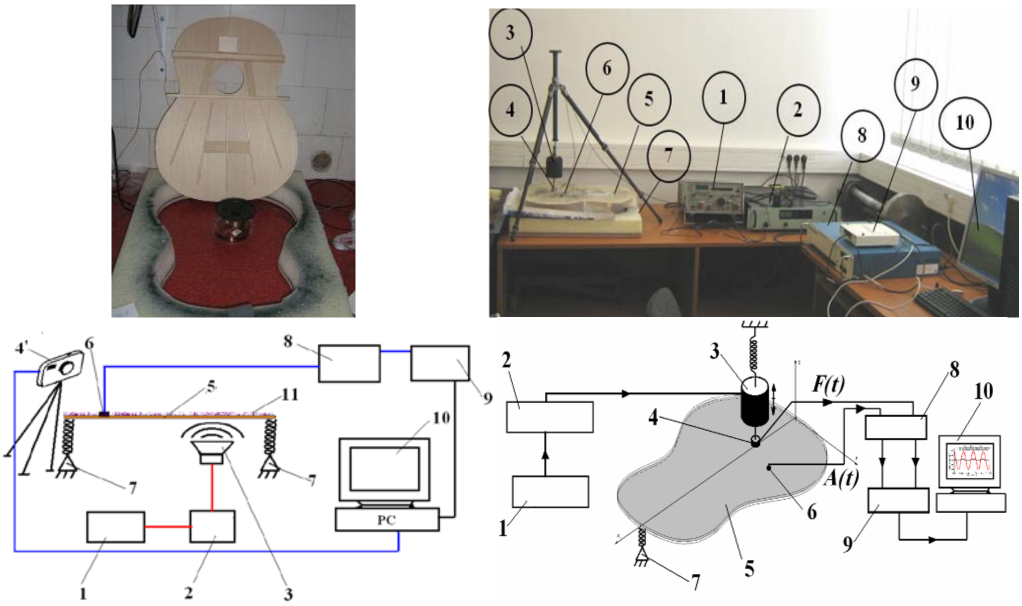
*Table 1.* **Types of studied plates**

| | **Case 1** | **Case 2** | **Case 3** | **Case 4** | **Case 5** |
|---|---|---|---|---|---|
| **Type of plate** |  |  |  |  |  |
| **Moisture content U [%]** | 7.8% | 8.1 % | 8.3 % | 8.2% | 8.4% |
| **Mass [g]** | 187.5 | 290 | 316 | 318 | 312 |

To analyse the influence of mass and stiffness were considered the guitar plates starting from simple plates to complex plates as the following cases: case 1 – simple plate without sound hole and fan braces, case 2 – plate with sound hole and with 3 transversal braces, case 3 – plate with 5 radial braces, case 4 – plate with 7 radial braces, case 5 – plate with 3 radial braces and 2 in V pattern (Table 1). For each plate were measured the average values of moisture content and mass.

Two types of tests were performed: non-contact test - with acoustic excitation using a loudspeaker as it can be seen in figure 2.a and a contact method - with mechanical vibrations of mini-shaker as in figure 2.b.

The methods used consisted of applying a harmonic excitation to the plate by means of loudspeaker (in case of test 1) and the mini-shaker (in case of test 2). The experimental stand was built according to the scheme in figure 2. Each structure (5) was freely supported on a foam device (7) and excited with a B&K mini-shaker or loudspeaker (3), located on a bridge area of the top plate (Stanciu , 2008). The frequencies of the harmonic force were: 110, 146.83, 196, 246.9, 329.2 Hz (specific to the strings of guitar frequencies) and 440 Hz (la – musical note), 588 Hz (third frequency of 196 Hz). The input data are displayed in Table 2.




*a)* *b)*

**Fig. 2.** Block diagram representation of the tests:
*1 - frequency generator; 2 - amplifier; 3 - vibration mass: loudspeaker(a), mini shaker(b); 4 - force transducer (b); 4' - photo camera; 5 - sample; 6 - accelerometers; 7 - spring support; 8 - conditioner; 9 - DAQ; 10 - personal computer for displaying and processing data*

The input signal was measured with a force transducer (4) and the forced vibrations of each structure (the output signal) were captured with three B&K 4517-002 type accelerometers (6) (measuring on the *z* direction) (Inta Ra, 2007). The captured signals were amplified and filtered through a conditioner (8), then were sent to the acquisition device (DAQ) (9) which was connected to the computer (10). The signal capture and display were achieved through the program developed in LabVIEW, and the data obtained under a numerical form were processed using Microcal Origin. To determine the modal shapes, the top plate of the guitar body was covered with a thin uniform layer of sand having a 100-150 grit size (Curtu, 2008).

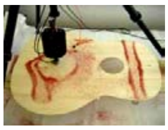
## 3. RESULTS

### 3.1. Chladni patterns

The modal shapes are given to the distribution of the significant nodal lines on the surface plate. The nodal line represents the points or areas which remain in equilibrium position during the vibration. There are many methods to determine the Chladni patterns: non contact - holographic interferometry techniques and with contact – using powder covered of plate.

In Table 2 some Chladni patterns are displayed. Reviewing modal forms obtained, it finds the following aspects: with increasing the frequency, modal shapes become more complex and tend to be similarly regardless of strutting system; the symmetry of modal shapes depends on the symmetry of wood microstructure; Chladni figures provide useful information about the capacity of plates to respond at different excitation frequencies; the modal shapes of various plates' structures differ in accordance with number, size and position of stiffening braces. All Chladni figures of different types of guitar plates present some nodal regions aligned with braces due to of considerable local increase in stiffness and mass due to the bracing system (Inta Ra, 2007). The modal shapes obtained by both methods are similarly as disposing of nodal lines at the same frequency.

*Table 2.* **The Chladni Figures for studied plates at frequency of 196 Hz**

| | **Case 1** | **Case 2** | **Case 3** | **Case 4** | **Case 5** |
|---|---|---|---|---|---|
| Plates before tests |  |  |  |  |  |
| Non contact test – with loudspeaker |  |  |  |  |  |
| Contact test – with miniskaher |  |  |  |  |  |

### 3.2. The Fourier Analyses

The signals from the force transducer and accelerometer were captured through DAQ. The data were processed in different types of charts representing: steady state vibration, the amplitude of the harmonic response, forced response of the plates, characteristics of frequency transfer function. Figure 3 presents the harmonic responses of plates with different stiffening patterns in time domain. It could be noticed that the dynamical behaviour of plates is governed by the same harmonic law as excitation force. The frequency responses of plates are displayed in figure 4 for each studied cases. The resonance of plate corresponds to the phase shift of $90^0$ and the value of resonance frequency is similarly with frequency of periodical applied force. The transfer function gives information on both the magnitude and relative phase between force and acceleration at measured point.

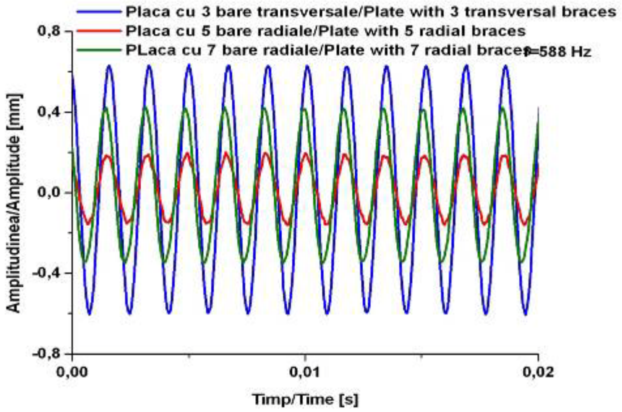



**Fig. 3.** Vibration behaviour of different structures

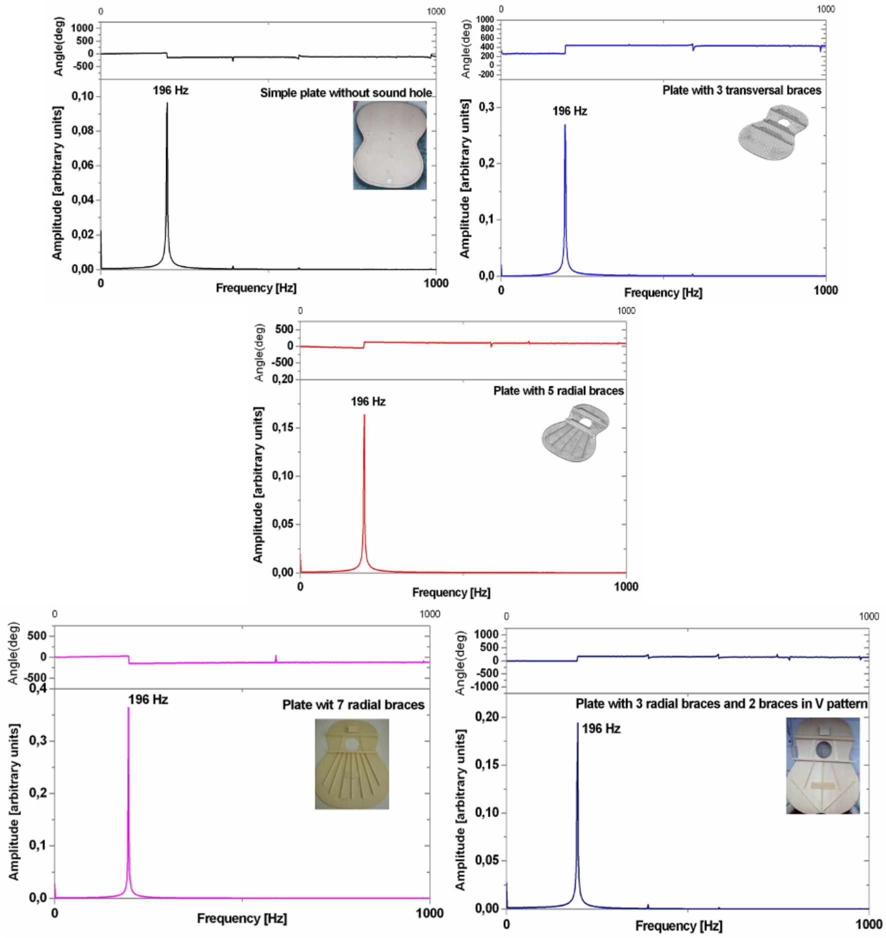



**Fig. 4.** The plots of frequency response function

Figure 5 presents the variation of radiated sound power for simple supported plates with different strutting systems. It can be noticed that the first peak corresponds with the resonance frequency, and the other ones (lower) correspond to the harmonics of first, second, third order. The curves of power spectral density regardless of braces pattern are similarly.

The differences of stiffness are obviously with increasing the frequency. Dynamical behaviour of the plates with 3 radial braces and 2 in V pattern (case 5) is characterized by numerous resonance frequencies as shown in figure 5.

Dynamic mass is another parameter which depends on stiffness, mass, materials of plates and boundary conditions. These mass spectra are very different for each plate as it can be seen in figure 6.

Because the measurement is only made at a single point, the dynamic mass spectrum alone does not illustrate the spatial distribution of a given vibratory mode of soundboard. These measurements are supplemented with Chladni figures presented in Table 2. The vibration properties of guitar plates which is an anisotropic plate, are much complicated than those of a homogeneous plate. Moreover the measurements of guitar soundboard which are not only anisotropic, but also have an additional bracing structure, are useful to study, even if these provided us a rough approximation to complete guitar body. In figure 6 is displayed the relationship between the dynamic mass spectrum and Chladni modes of soundboard with 3 transversal braces.

## 4. CONCLUSION

The paper presented the experimental research on dynamic behaviour of plates with different strutting systems used in construction of classical guitar. Monitoring the dynamical behaviour of guitar's plates as an individual structure, the diagnoses of acoustical features of guitars can be made. In these researches the freely supported plates were considered. In other boundary condition, the results will be different.

The study has made both theoretical implications as especially practical. Theoretically, there are explained the dynamic phenomena of thin plates in conjunction with geometry, physical characteristics and stiffening bars applied on them. In practical terms, the study contributes to the optimization of the acoustic qualities of guitars through the quality control of the fabrication sequence starting with preparing material wood used in the manufacturing of musical instruments.

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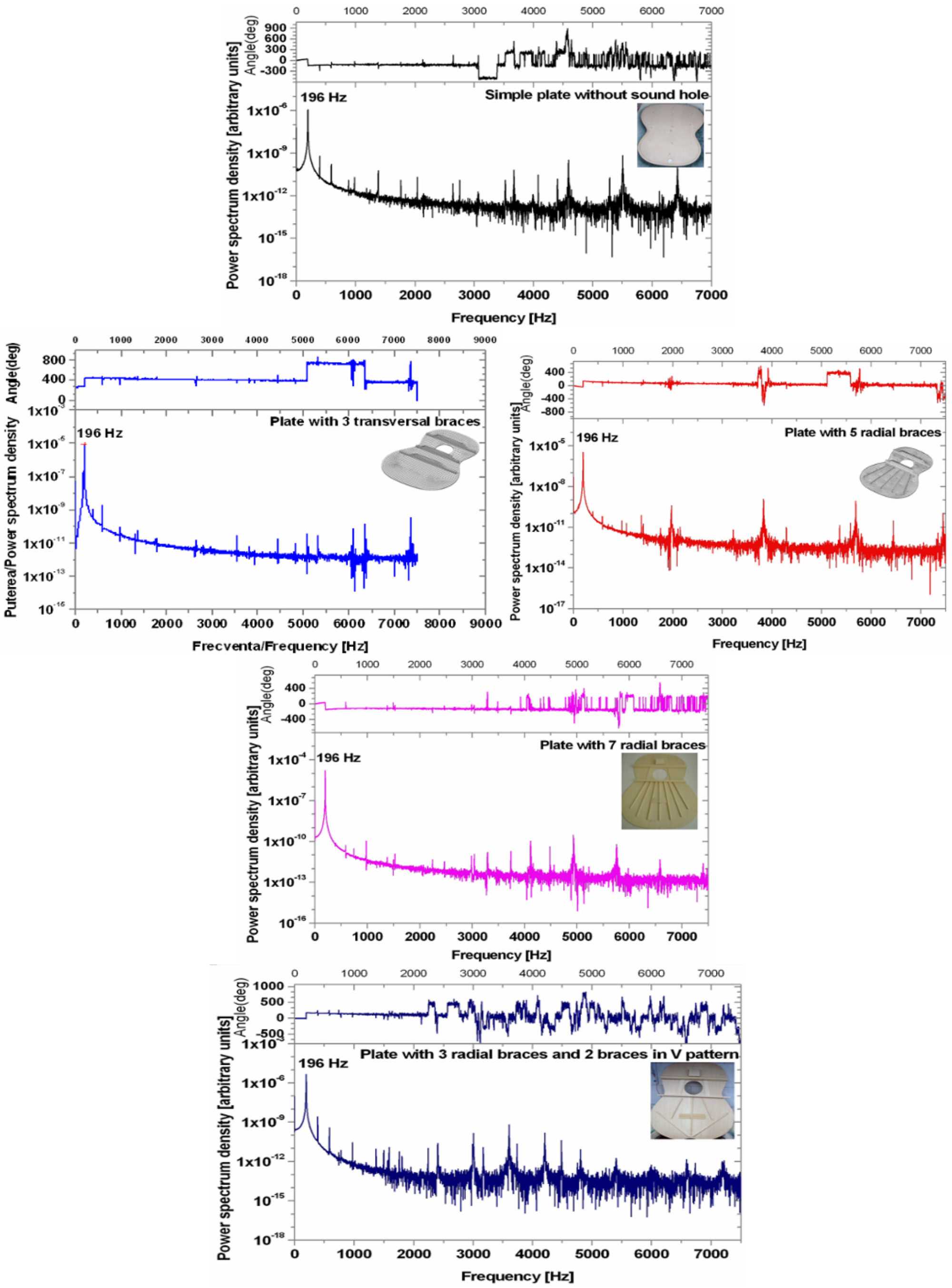


**Fig. 5.** The power spectral density

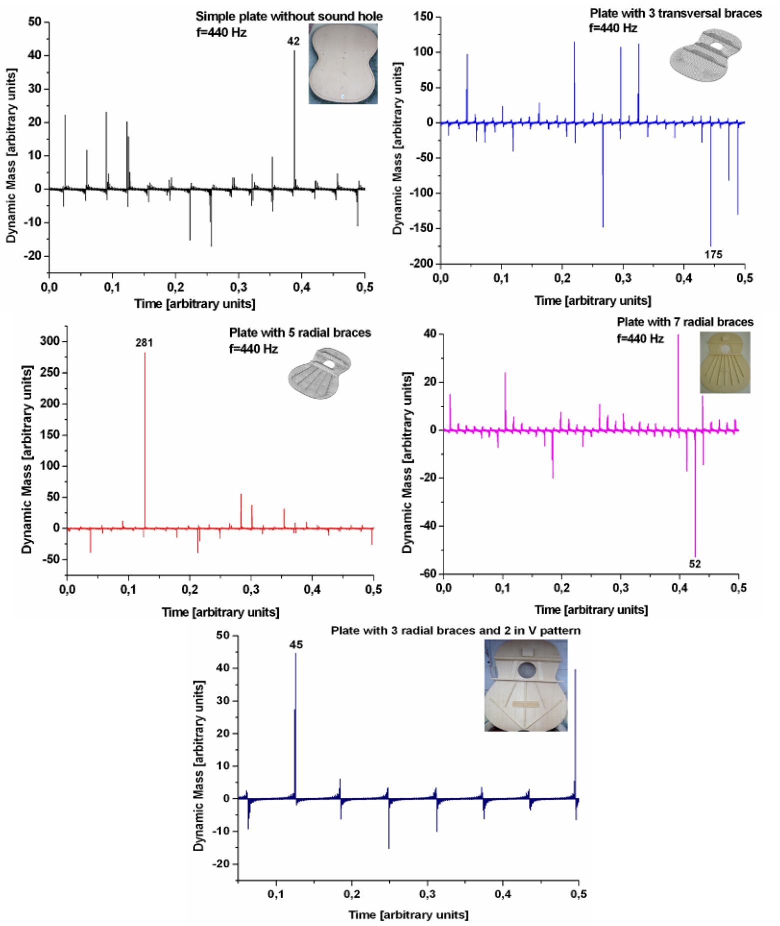


**Fig. 6.** Dynamic mass spectra of studied plates

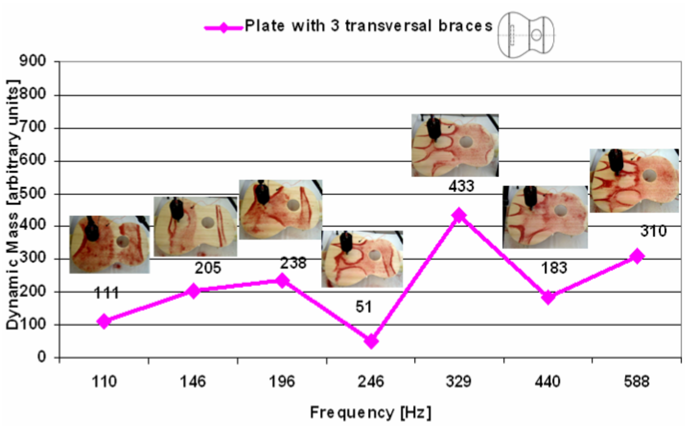


**Fig. 7.** Illustration of relationship between the dynamic mass spectrum and modal shapes of plate with 3 transversal braces

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