Modal Analysis of Different Types of Classical Guitar Bodies

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Abstract: Resonant frequencies and Chladni patterns of different types of classical guitar bodies were investigated to continue and further develop the understanding of the tonal qualities of guitars. The acoustic boxes with four types of strutting systems were analyzed. For this, a B&K mini-shaker, to excite the structures, and three B&K 4517-002 accelerometers located on top, at the back and on the sides of the sound box were used. The input and output signals were collected with a Data Acquisition device (DAQ) and processed to discover resonant frequencies and harmonics. During the experiments, Chladni patterns were obtained using powder sand on the surface. The method used does provide some insight regarding the vibrations of classical guitar bodies such as the influence of the strutting system on the modal shapes and dynamic response. The paper carries on the theoretical studies presented in works [4], [5], [6], [14], [15], [16], with experimental research.

Key-Words: Chladni figures, resonant frequency, modal analysis, classical guitar

1 Introduction

The guitar represents a complex vibrating system. One of the most important parts of a guitar is the body [7]. This is made up of ligno-cellulose plates (top plate, back plate, ribs) which vibrate, radiate and amplify the sounds [3].

The plates must have a thin thickness in order to vibrate under the exciting forces of strings. At the same time, these structures must resist to the cyclic stresses [4]. Both requirements are fulfilled with the help of the stiffening braces glued on the top plates.

The paper presents the experimental results regarding the influences of the number of braces and of the strutting system on the modal shapes and dynamic behaviour of the acoustic boxes.

In spite of the difficulty of analyzing all phenomena which occur in guitar bodies, the present research can be beneficial to predicting the tonal qualities of classical guitars. These results are used for the optimization of guitar bodies manufactured by S.C. Hora S. A. Reghin Romania.

2 Literature Review

The natural and resonance frequency as well as the modal shape of the plates of a guitar have been studied by many researchers, but each approach differed according to the objectives of the analyses, to the method used, to the types of guitars analyzed or to the features of the materials the guitars were made of.

Torres and Boullosa (2006) are the authors of numerous articles regarding the modal analysis and the vibration behaviour of a classical guitar in different construction stages using the finite element method (FEM) [4], [17].

H. Wright and Bernard Richardson, alongside with some of their colleagues at Cardiff University, performed studies on the classical guitar to establish the influence of individual features on the modal shapes and frequency [21].

Russel and Pedersen (1999) investigated the modes of vibration of various guitars using a force hammer to excite the structures [11], [12].

Paul M. Shaheen (2004) focused on the sensitivity analyses of the folk guitar simulating the building process [13].

Serghei Vladimirovici (2006) researched, using the FEM method and the experimental method, the influence of the Russian strutting systems on the dynamic behaviour of the plates [20].

Becache, Chaigne, Derveaux and Joly studied the time numerical modelling domain of the fluid – the structure interaction of a guitar [2].

Stanciu, Curtu and Itu (2008) investigated the dynamic behaviour of different types of plates as individual structures and of plates from guitar bodies using the FEM method [14], [16].

3 The Experimental Method

To perform the experiment, four types of acoustic boxes, from the point of view of the stiffening braces pattern, were used, in accordance with the guitars manufactured by S.C. Hora S. A. Reghin Romania [23], namely: case 1 (plate with 3 transversal strips to the axis), case 2 (plate with 5 braces), case 3 (plate with 7 braces) and case 4 (plate with 3 radial braces and 2 in a V pattern) (Fig.1).The neck and the bridge were neglected.

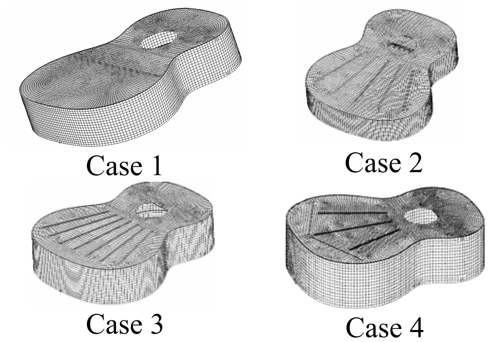
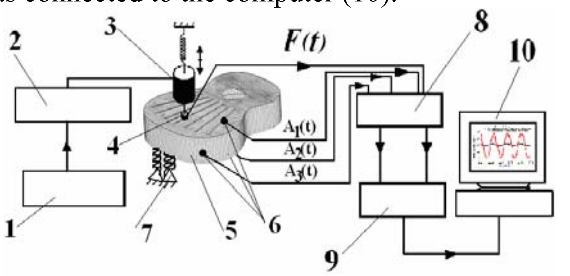


Fig.1. Types of strutting systems of guitar plates

The method used consisted of applying a harmonic excitation to the structures by means of the mini-shaker. The experimental stand was built according to the scheme in Fig. 2. Each box (5) was freely supported on a foam device (7) and excited with a B&K mini-shaker (3), located on a bridge area of the top plate. 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), 720, 980 Hz. 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). 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).



1-frequency generator
2-amplifier
3-vibration mass
4-force transducer
5-sample (acoustic box)
6 -accelerometers
7 –spring support
8 –conditioner
9 – DAQ
10 – personal computer for displaying and processing data

Fig.2. Block diagram representation of the test

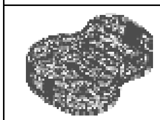
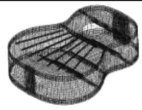
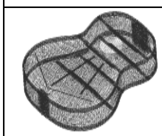
The signal capture and display were achieved through the program developed in LabVIEW, and the data obtained under a numerical form were processed using Microcal Origin [10]. To determine the modal shapes, the top plate of the guitar body was covered with a thin uniform layer of sand having a 100-150 grit size.

3 Results and Discussion

3.1. Chladni patterns

The modal shapes of the top plates, known as the Chladni pattern, are given by the distribution of the significant nodal lines on the surface of the structure. The nodal line represents the points or the areas which remain in an equilibrated position during vibration [17], [19]. During vibrations, each pattern of the strutting system, characteristically, has nodes and antinodes at various locations on the body of the guitar [5], [14], [15], [16]. There are many methods to determine the Chladni patterns: the non contact method – using holographic interferometry techniques – and the contact method – using powder to cover the plate. In this research we used the second technique, as shown in Tabel 1.

Table 1.The Chladni patterns for the studied acoustic boxes

Types of acoustic boxes	**110 Hz**	**720 Hz**
 **Case 1**		
 **Case 2**		
 **Case 3**		
 **Case 4**		

Comparing the results obtained (Table 1), it can be noticed that there are a lot of similarities regarding the modal shapes of low frequencies (110, 146, 196 Hz). With the increasing of the frequency, the

Chladni patterns become more complex and different from one structure to another. The acoustic box with three transversal braces (case 1) has a different dynamic behaviour as compared to the other structures. What was applied in point of analysis was the quantification criterion to establish which guitar bodies have a good dynamic behaviour. For this, we gave notes from 1 to 4 for each Chladni model obtained as a result of the 10 excitation frequencies. Note 4 was awarded to the clearest and to the most shaped figure, note 3 was given to a clear and enough visible shape, note 2 was for weak visible figures, and note 1 was received by the unclear figure, without outlined forms. In Table 2 the assessment of the modal shapes for each guitar body tested are presented.

Table 2. Quality evaluation of the modal shapes

	Case 1	**Case 2**	**Case 3**	**Case 4**
1	3	3	4	4
2	2	3	3	3
3	4	4	4	2
4	4	4	4	4
5	2	4	4	3
6	1	4	4	4
7	2	3	2	3
8	4	3	2	3
9	3	3	4	4
10	4	4	3	4
Total	**29**	**35**	**34**	**34**

From Fig. 3 it can be noticed that the best dynamic response to forced vibrations was obtained in the case of the acoustic box with 5 stiffening braces. Cases 3 and 4 are similar which means that the dynamic response can be improved with the change of the materials, with the thickness of the material or with the pattern of the braces.

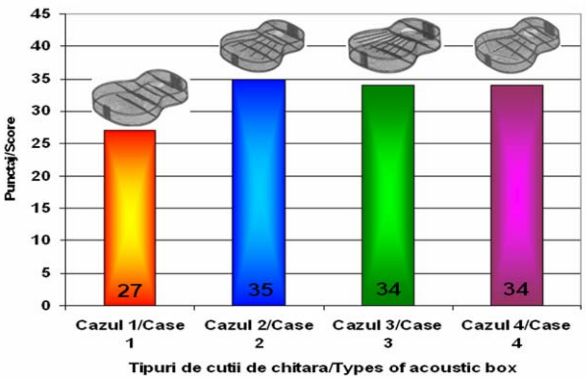


Fig. 3. Comparison of various guitar boxes after analyses based on quantification criteria

The experimental and numerical (FEM) results regarding the modal shapes are similar. In Fig.4 there are shown the Chladni patterns in case 4.

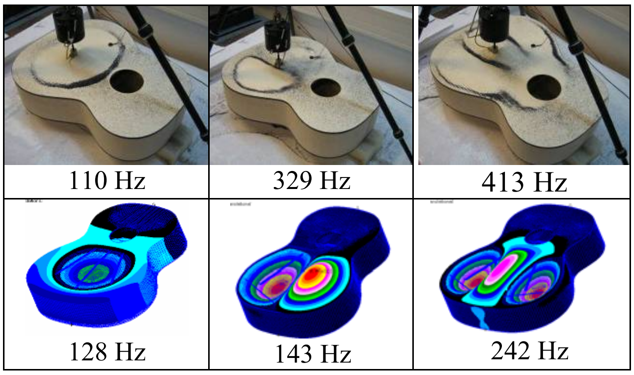


Fig. 4. Comparison between experimental research and the FEM analysis in case 4

3.2. Frequency Response

The signal from both the force transducer and from the accelerometer was captured through the DAQ device and displayed with a program developed in LabView. The data were processed in different types of charts representing: the steady state vibration, the amplitude of the harmonic response, the forced response of the plates, the characteristics of the frequency transfer function, the power spectrum density (Fig. 5…12).

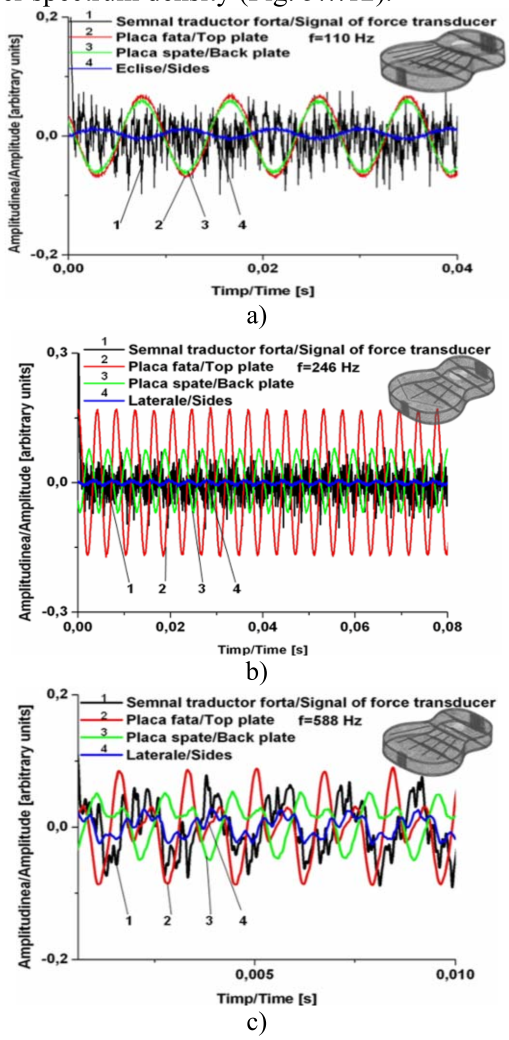


Fig. 5. Forced response plot in time domain

The top, back and side plates respond with harmonic vibrations to the harmonic signal of the excitation force (Fig. 5 a, b, c). In terms of acoustic resonance, the braces on the top plate (in what number, pattern, material and dimensions are concerned) are designed to ensure a wider resonance field.

The acoustic performance of the classical guitar is given by the interaction between the top, back and side plates and the enclosed air. Due to the geometrical shape of the guitar and to the presence of the strutting system (in what number, pattern, material and dimensions are concerned), the inside volume of the air has an indefinable shape. Acoustically speaking, the irregular form presents numerous zones with a wide range of natural frequencies able to respond to forced vibrations. In terms of acoustic resonance, the braces on the top plate are designed to ensure a wider resonance field. Thus, the guitar body gains a non-selective radiator being able to vibrate for a wide band of frequencies [18]. Irrespective of the strutting system, the top plate behaves as a low damping receiver; the maximum magnitude of the vibrations is high compared to that of the back plate which is a high damping receiver. In this case, the resonance curve is moving towards low frequencies.

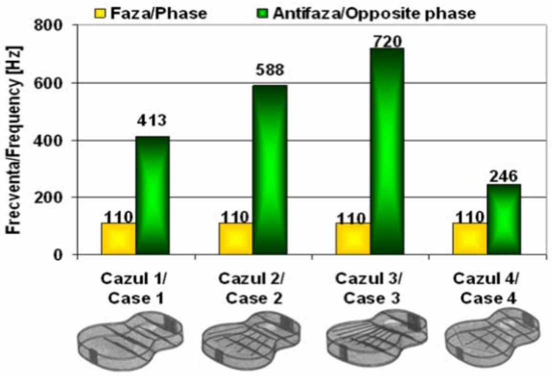


Fig. 6. Phase and opposite phase frequencies

From Fig. 5 there can be noticed the phase and the opposite phase of the main parts of the acoustic box of the guitar. The plates go into phase at low frequencies (110, 146 Hz) regardless of the braces' pattern. Contrary, the opposite phase is obtained at frequencies of different ranges from middle to high (246, 413, 588, 720 Hz) as shown in Fig. 6.

Figures 7, 8, 9 and 10 present the systems responses in frequencies domain. Fourier analyses show that the guitar bodies come into resonance at excitation frequency. It can be noticed that the first peak corresponds to the resonance frequency, and that the others, the lower ones, correspond to the harmonics of the first, second, third order (Fig. 7, 8, 9, 10).

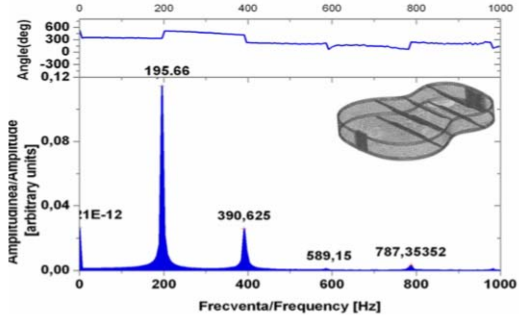


Fig. 7. Frequency response of the top plate in case of the acoustic box with 3 transversal braces

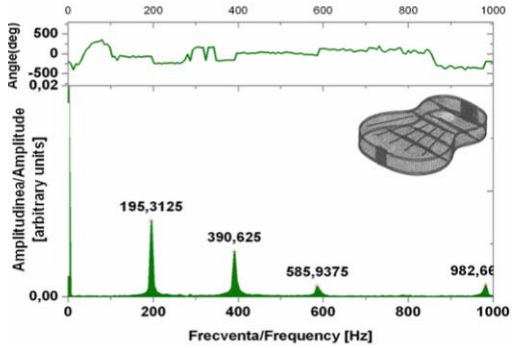


Fig. 8. Frequency response of the top plate of the acoustic box with 5 radial braces

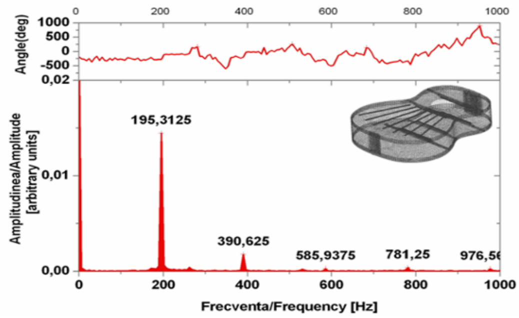


Fig. 9. Frequency response of the top plate of the acoustic box with 5 radial braces

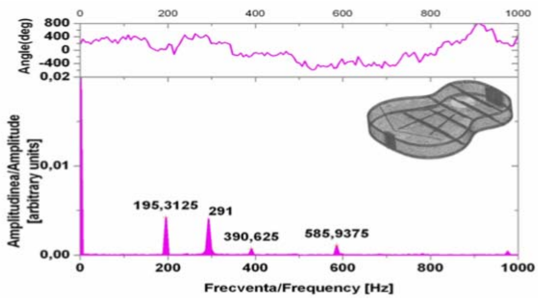
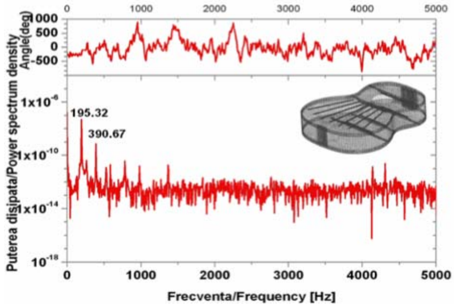
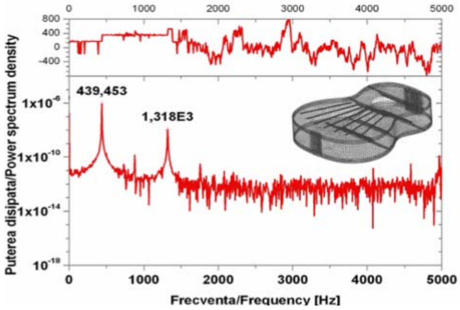


Fig. 10. Frequency response of the top plate – case4

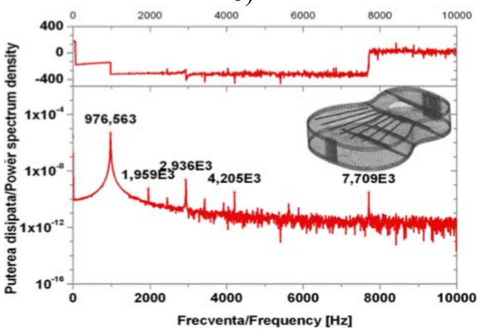
For example, the plots of power spectral density for different frequencies (196, 440, 980 Hz), in case of the acoustic box with 7 radial braces, is illustrated in Fig. 11 a, b, and c. The dissipation of the energy of the signal depends on the materials of the plates, on the inner structure of the guitar body, on the frequency of the forced vibrations and on the sound generator. In Fig. 11 it can be noticed that the first peak corresponds to the resonance frequency, and that the other one, the lower one, corresponds to the harmonics of the first, second, third order.



a)



b)



c)

Fig.11. The power spectral density for different excitation frequencies

Fig. 12 shows a comparison between the dissipation curves of the signal power in all studied cases. All structures resonate at excitation frequency (440 Hz) but the way in which the energy of the signal decreases is different from one structure to another.

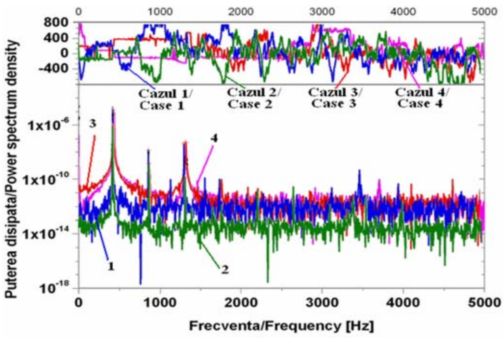


Fig. 12. Comparison between curves of power spectrum density in studied cases

At lower frequencies, some non-linear phenomena appear which are responsible for the frequency radiated by the back plate and for the deep frequencies of the enclosed air from the cavity. With the increasing of the frequency, the guitar body tends to vibrate in the linear domain, the soundboard producing a bright and light sound.

4 Conclusion

The paper presented the experimental research on the dynamic behaviour of the coupling plates of a guitar body. The neck, the bridge and the strings were neglected. The experiments simulated the strings' action by means of a mini-shaker. In contrast to real phenomena, where the strings produce harmonic excitation to the damped system, the test used undamped harmonic vibrations. Under the given circumstances, our results can be compared to the ones of some other researchers, under similar laboratory conditions [8], [21].

The experiments highlighted the influence of the strutting system on the dynamic behaviour of the guitar body. The examination of the Chladni figures showed the modification of the modes with the increasing of the number and of the pattern of the braces. At similar frequency, the structures responded differently because each acoustic box resonated at another frequency (approximately at natural frequency). The normal frequency influences the quality of the sound in terms of the balance in timbre. Therefore, one of the acoustic criteria regarding the quality of a guitar is for this one to be able to resonate at a rich range of harmonics and to assure an unequal filter of the tones.

All guitar bodies vibrate harmonically at harmonic excitation. The soundboard amplitudes of the acoustic boxes varied under the even parameters of the input signal. Fourier analyses showed that the studied structures vibrated at resonance frequencies and harmonics. The power spectrum densities were identified for all structures, which mean that there can be some deviations from the eigenmodes and eigenfrequency of the individual parts (top plate, back plate, ribs), an observation which is similar to Bader's conclusion [1].

The future work consists in carrying out measurements of the acoustic power of different types of a guitar's body, in the determination of the natural frequency of a guitar without strings and, finally, in the optimization of the strutting system in order to improve the acoustic quality of the classical guitar.

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