THE NUMERICAL MODELING OF THE ACOUSTIC PLATES ON THE GUITAR STRUCTURES

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ABSTRACT: The paper focuses on the analyses of the dynamic behaviour of the lignocellulose composites from the plucked musical instruments structures, using the finite element method. Firstly, we modeled the proper geometry of the structures from plates, respective the body of the classical guitar in accordance with the typo-dimensions used at the musical instruments factor SC Hora SA Reghin Romania. The second step consists of the dynamic analysis with FEM, using the Patran-Nastran soft. It was analyzed the influences of the different parameters of the acoustic plates such as the thickness, the features of the materials (different wood species, plywood), the positions of the braces. From the analyses of the behaviour of the structures to the cyclic stresses, it can be noticed that the acoustic performance of the classical guitar depends on: the features of the microstructure, the physical, mechanical and dynamic characteristics of the materials used for the plates.

The results were comparing to the dates and conclusions comprised in the references [5], [6], [7], [8], [9], [10], [11], [12]. The conclusions of the numerical modeling contribute to the optimization of the shape and materials of the guitars

Key words: finite element method (FEM), lignocellulose plates, vibration modes, amplitude, boundary conditions, normal frequency.

1. INTRODUCTION

In the string instruments construction (classical guitar, acoustic guitar, violin, cello, mandolin) are used lignocellulose plates with acoustic properties. These plates

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are different from the point of view of the complex geometry, the dimensions, the materials (wood, plywood) and the physical, mechanical and dynamical properties, the density, the added elements (bracing) fixed in different patterns (Fig. 1), the finishing [4].

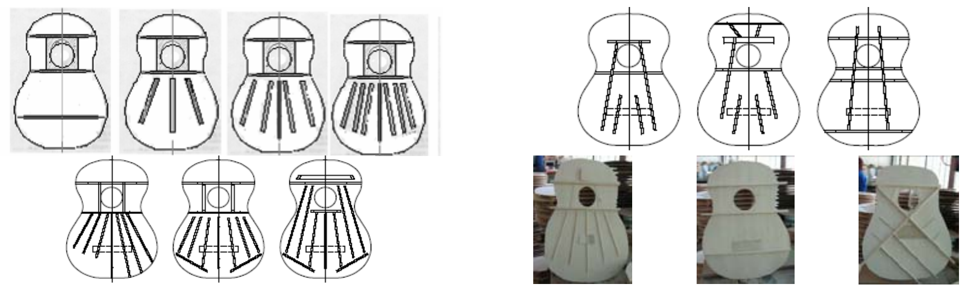


Fig. 1. Types of bracing pattern of guitar plates

One of the most used and appreciated material is wood both acoustics quality and aesthetical values. Related to species we mention: spruce, cedar, and other softwood species with resonance properties, cypress, wavy maple, sycamore, pernambuco wood, mahogany, rosewood and others appreciated for grain and texture, beech, walnut, black locust, ebony used for wear resistance [2]. Nowadays are also used the ligno-cellulose composites as: plywood, LSD (densified laminated boards), MDF (medium density fiberboards), honeycomb cardboard, a.o.). The first types are used for high quality instruments (maestro, professional, special), the second for beginner musicians (students, amateurs, school-boy).

2. THE NUMERICAL MODELING

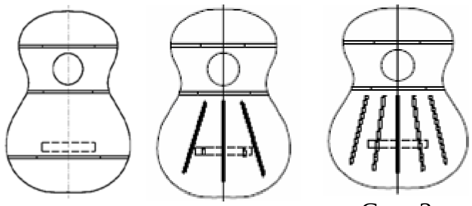
The paper focuses on the dynamic behavior (natural frequency, normal modes, amplitude, modal shapes) of the plates obtained with finite element method (FEM). This assumes more steps which we were run.

The geometry modeling

For dynamic analyses of acoustic plates, we designed three types of plates with the same sizes, but with different bracing patterns: simple plates (case 1), plates with 3 braces (case 2), and plates with 5 braces (case 3) (Fig. 2). It was used the typo-dimensions of the Romanian classical guitar, 4/4 size which are manufactured at the S.C. Hora SA Reghin, Romania.

2.2. Finite element modeling

For FEM analyses was used the Patran-Nastran soft. The plates were modeled with SHELL elements (Fig. 3). Regarding to the boundary conditions, the plates were clamped on the edges [7], [12].



Case 1 Case 2 Case 3

Fig. 2. Types of design plates

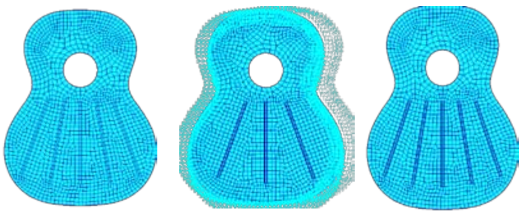


Fig. 3. Step of plates meshing

The variables were: the Young’s Modulus (*E*), the thickness (*h*), the density (ρ). In the Table 1 are presented the values of the varying parameters. The values were selected from the references [2], [3]. The Poisson’s ratio was maintained constant with value 0.38. The analyses focus on the first fourth normal modes of the plates and amplitudes for cases 1, E = 10241 MPa, h = 2.5 mm, ρ = 450 kg/m^3 (Fig. 4). In figure 5 are presented the superior normal modes obtained with FEM, for case 1.

Table 1. **Values of the varying parameters**

<table>
<tr><th>Thickness h, mm</th><th>1.5</th><th>2</th><th>2.5</th><th>3</th><th>3.5</th></tr>
<tr><td rowspan="3">Young’s Modulus E, MPa</td><td colspan="5">10241</td></tr>
<tr><td colspan="5">12000</td></tr>
<tr><td colspan="5">14000</td></tr>
<tr><td rowspan="5">Density ρ, kg/m³</td><td colspan="5">380</td></tr>
<tr><td colspan="5">400</td></tr>
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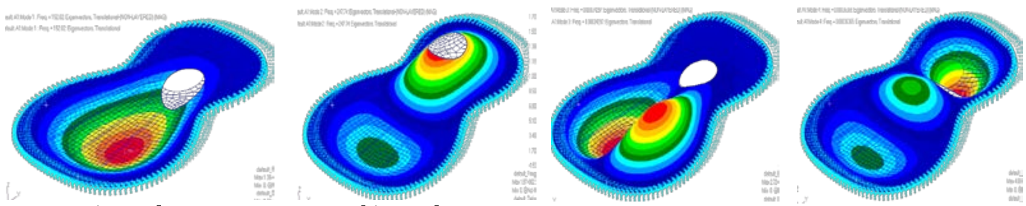
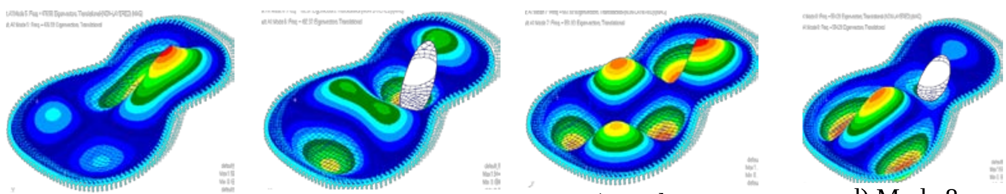


a) Mode 1 b) Mode 2 c) Mode 3 d) Mode 4

Fig. 4. The first 4 modal shapes for simple plates with clamped edges



a) Mode 5 b) Mode 6 c) Mode 7 d) Mode 8

Fig. 5. Next normal modes of the simple plates

3. THE RESULTS

After numerical modeling, were obtained numerous results which we processed and represented on charts (Fig. 6 … 12). The charts show the influence of:

- Young's Modulus (E),
- thickness (h) of the plates,
- density (ρ) of the material,

on the values of the amplitudes (A) and the frequency (F) of vibrations for the three cases analyzed. The results were comparing to the dates and conclusions comprised in the references [5], [6], [7], [8], [9], [10], [11], [12]. The conclusions of the numerical modeling contribute to the optimization of the shape and materials of the guitars.

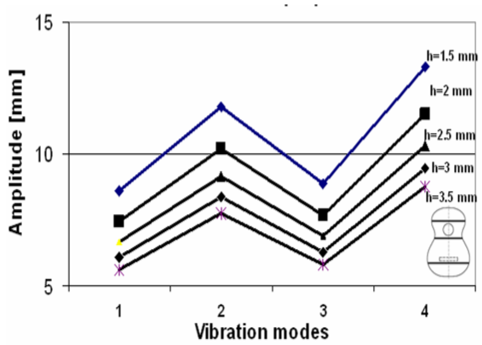


Fig. 6. The variation of the amplitudes with the thickness of the simple plates

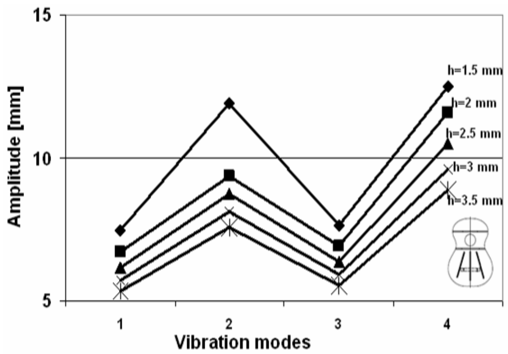


Fig. 7. The variation of the amplitudes with the thickness of the plates with 3 bracing

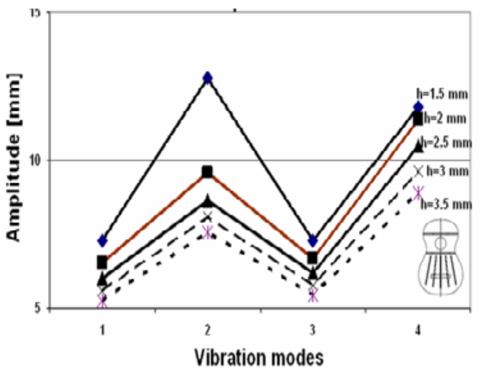


Fig. 8. The variation of the amplitudes with the thickness of the plates with 5 bracing

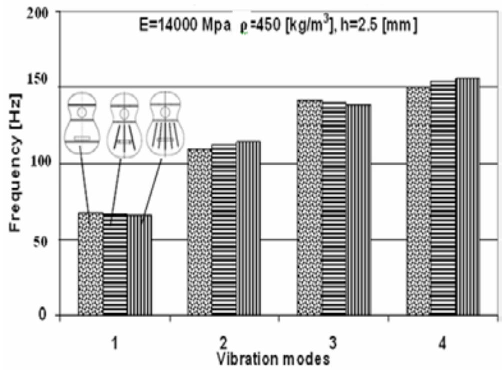


Fig. 9. Comparison between frequencies of three cases of plates

4. CONCLUSIONS

From the dynamic analysis of different plates can be noticed that:

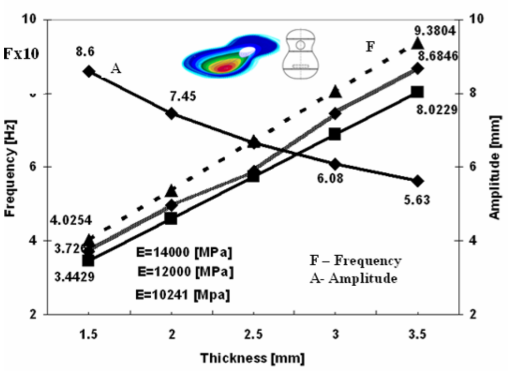


Fig. 10. The variation of frequencies and amplitude with increasing the thickness of plates – case 1, first normal mode

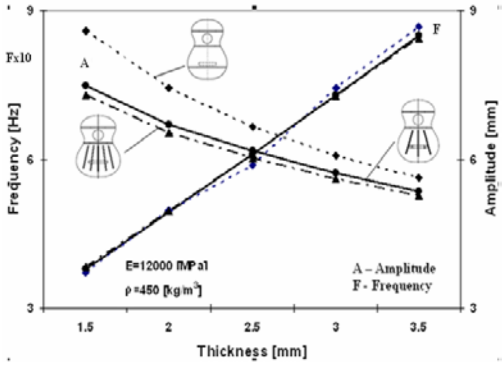


Fig. 11. The variation of frequencies and amplitude with increasing the thickness of plates – all cases, for first normal mode, E = 12000 MPa

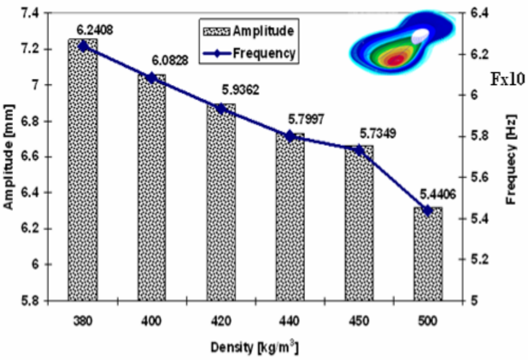


Fig. 12. The variation of frequency and amplitude with the density, for simple plates, first normal mode, E = 10241, MPa, h =2.5 mm

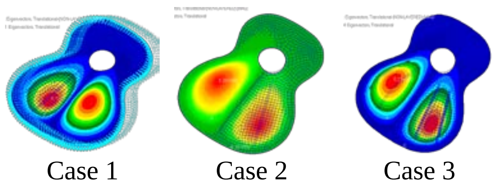


Fig. 13. Modal shape for different types of plates, mode 3

- The amplitude decreasing with increasing the thickness of plates in all cases (Fig. 6, 7, 8);
- For the same density, thickness and Young's Modulus, but with different mass (respective the three cases considered), the frequency increasing with increasing of the normal mode;
- The normal frequencies increasing with the increasing the thickness and the amplitudes decreasing;
- With rise of density, the frequencies and amplitudes decreasing;
- The big values of the Young's Modulus increase the natural frequency;
- The geometry and the braces pattern change both the stiffness of plates, the modal shapes, the amplitude and the frequency (Fig. 13);
- For different Young's Moduli, the same thickness and the same density, the amplitudes are constants.

The dynamic behavior of the plates depends on the physical, mechanical (elastic) and dynamical characteristics of the wood species used, namely: the geometry and the sizes of the elements, the density of materials, the moisture content, the Young's modulus, the stiffness modulus, the shear resistance, the bending strength, the sound velocity in wood, the acoustic impedance, the acoustic radiation, the quality factor. Between these exists a power connection which assures the static, dynamic and acoustic equilibrium of the musical instrument.

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