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NUMERICAL MODELLING OF THE ACOUSTIC PLATES AS CONSTITUENTS OF STRINGED INSTRUMENTS

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Abstract: *The aim of this paper is to analyze through the finite element method (FEM) the dynamical behaviour of the ligno-cellulose composite plates from the structure of guitar.*

First it had been done the geometrical modelling of the structures from the plates, as the body of the classical guitar – size 4/4. Then the different structures were analyzed with finite element. The dynamical response had been obtained for different types of structures of plates, from the point of thickness, of the used material and of the top braces.

Through analyzing and comparing the normal modes of the fixed edges plates and the structures' response to the action of the cyclic stresses it had been noticed that the acoustic performances of the classical guitar are influenced by many factors.

Key words: finite element method (FEM), *ligno-cellulose composite plates, modal shapes, natural frequency*

1. ABOUT THE MECHANICS OF THE GUITAR

Stringed instruments are very complex structures from the mechanical, dynamical, technical and technological point of view, its constituents having properties of resistance, rigidity and also acoustical and aesthetical properties in accordance with the field quality requirements. The structure of the stringed instruments is made up of three subassemblies: the acoustic box, the neck and the strings [3]. The acoustic box amplifies the musical sounds and it is made up of the top plate, back plate and the sides. 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. The transfer of the vibration energy of the strings is done through the solid system (s_1 – string) - solid (s_2 – bridge) - solid (s_3 –sound board) – fluid (f_1 – the air from the cavity) - solid (s_4 - back) - solid (s_5 - side) - fluid (f_1 – the air from the cavity and the sound hole) (Fig.1). Thus, the pressure of the air from the box is periodically modifying. Under the boundary conditions the acoustic waves are reflected and emitted in all directions by the walls of the box, thereby producing a composition of acoustic waves under a very rich spectrum of harmonics. The guitar's body transforms the high pressure vibrations from the string into low pressure vibrations of the surrounding air making this way an "impedance balancing" phenomenon [6].

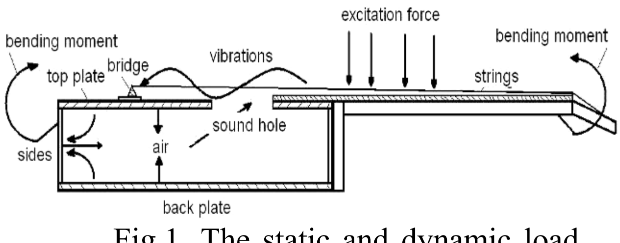


Fig.1. The static and dynamic load of the guitar's mechanical structure [8]

The speed emission of acoustic waves through solid (string-bridge-plate-box) is higher than the one through air, therefore the mechanical structure of the instrument influences the acoustic quality.

In the construction of stringed instruments (classical guitar, acoustic guitar, violin, violoncello, mandolin, balalaika etc.) there are used plates only with some acoustic qualities [8], [9]. These plates differ one from another through a series of characteristics: complex geometry, varying dimensions, different types of coating, materials with physical, mechanical, dynamical and acoustical properties, constructive elements (resonance and stiffening braces disposed in different patterns)- Fig.2. [4], [7], [10].

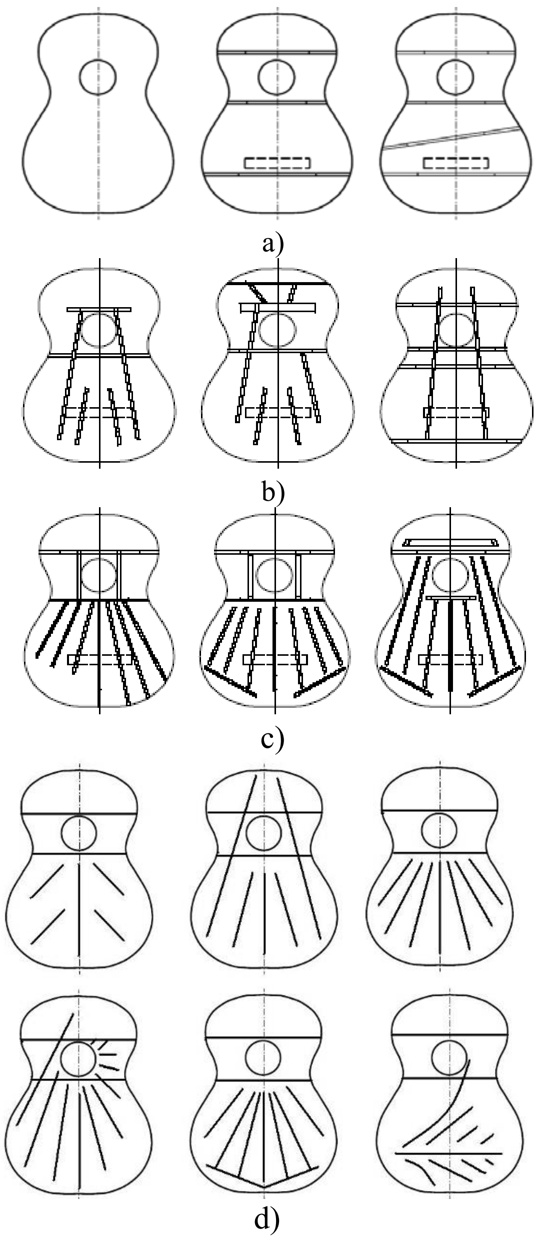


Fig.2. Types of disposing pattern of the resonance braces on the guitar plate

2. THE RESEARCH'S OBJECTIVES

The research's objectives are: producing the geometrical models of the acoustic plates as constituents of the guitars made in our country; establishing the type of finite element used for numerical modelling of the acoustic plates; analysis with finite elements method (FEM) of the plates' dynamical behaviour in the case of different parameters' variation (thickness, number of stiffening braces, density and elasticity modulus of the plate's material); studying the influence of the mentioned factors upon the values of fundamental frequencies and of the first 10 modal shapes.

2.1 The construction of the geometrical model.

The classical guitar size 4/4 was geometrically modelled according to the dimensions specified by the factory S.C. Hora S.A. Reghin [12] into 3 types of top plates: the simple plate, the plate with 3 resonance braces and the plate with 5 resonance braces (Fig. 3).

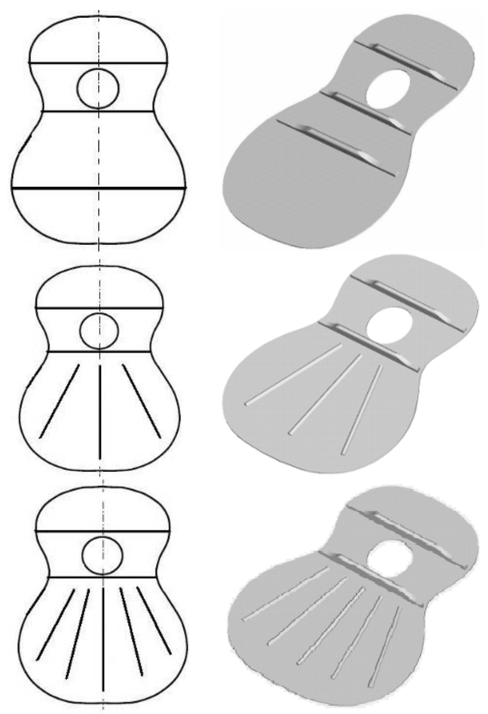


Fig.3. Versions of plates geometrically modelled for FEM analysis

2.2 The construction of the numerical model

For the dynamic analysis with FEM it was used Patran-Nastran 2004 package performing the modelling and the analysis of the plates in the 3 ways suggested in Fig.3. The plates were modelled with shell type elements with 4 nodes (Fig. 4) being fixed edges under the conditions of a variation of different parameters: *Young's* modulus E, density ρ and thickness h. The dynamical analysis sought the frequencies, the amplitudes and the modal shapes variation of the ligno-cellulose composite. It was noticed a variation of the thicknesses (h=*1.5, 2, 2.5, 3, 3.5 mm*), of the Young's modulus (E= *10000, 12000, 14000 MPa*) and of the density (ρ= *350, 400, 450, 500 kg/m*^{3}) but keeping constant the Poisson's coefficient (υ=0.36) [2], [5], [7].

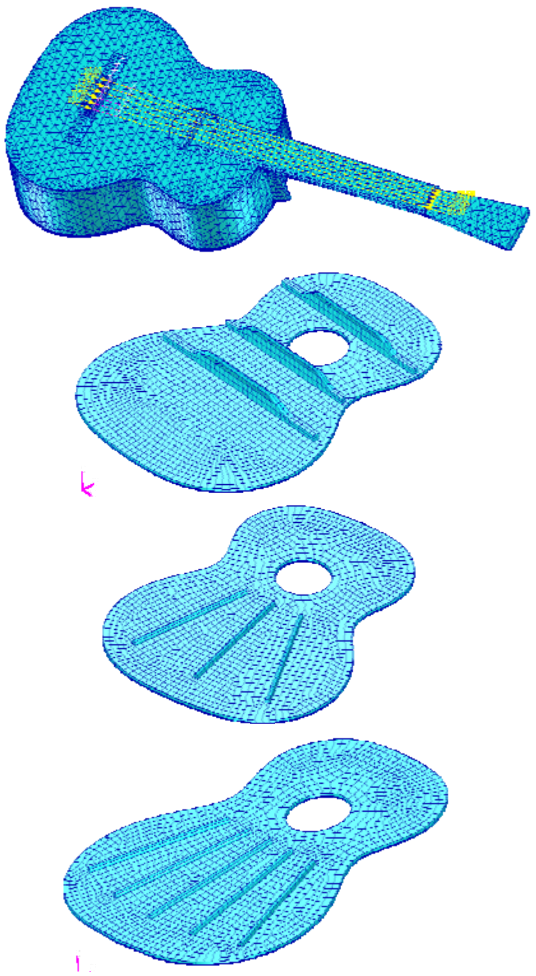


Fig.4. Numerical modelling with finite element of the three versions of modelled plates

2.3 Finite element analysis's results and their interpretation

As a result of the analysis with FEM numerous outcomes were obtained: modal shapes of the normal modes of vibrations (Fig. 5), the frequencies $f_{1...6}$ and the amplitudes' values for the first 6 modes which were analysed and summarized as diagrams.

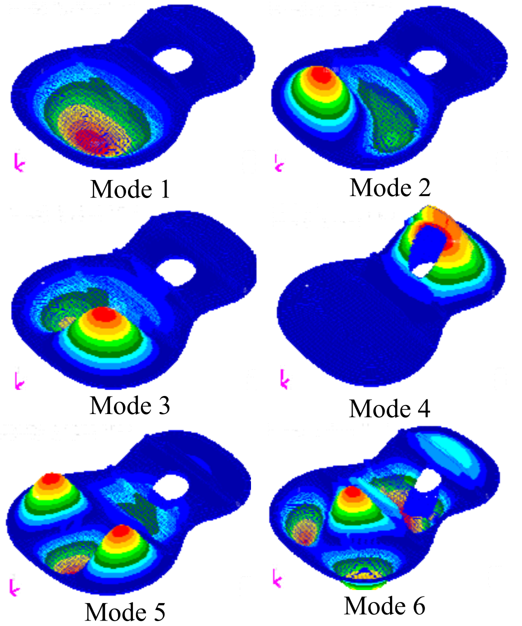


Fig.5. Modal shapes of the simple plate with the Young's modulus E=12000 MPa, thickness h=2.5 mm and density ρ= 450 kg/m^3

Then the research's results were compared to the ones from the specialized literature in this field.

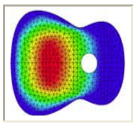
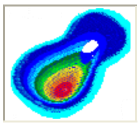
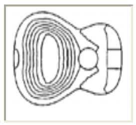
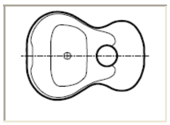
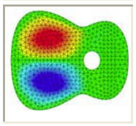
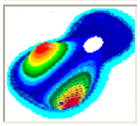
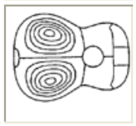
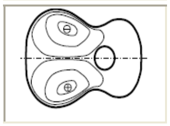
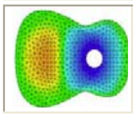
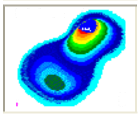
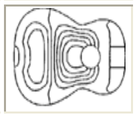
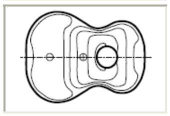
Bécache 2005	Stanciu 2008	Wright 1996	Vladimirovici 2004
			
			
			

Table 1. A comparison between the results relating to the normal modes of vibration obtained by different authors

Comparing the modal shapes obtained following the FEA to the ones from the technical literature, as it can be seen in the Table 1 it can be noticed that the results obtained by the authors are almost similar to the ones obtained by these researchers [[1]], [[10]], [[11]].

The existing small differences are due to the values of the elasticity modulus used by different authors, to the plates' thickness and to the mode of digitization in finite element depending on the soft, but are also due to the studied guitars' models (plates).

From the Fig. 6 it is noticed that the frequencies increase with about 25% for the same thickness (h=2.5 mm) and density of the plate (ρ=450 kg/m^3), along with an increasing elasticity modulus with 40%. The ribs' number is bigger, the vibrations' frequencies are smaller.

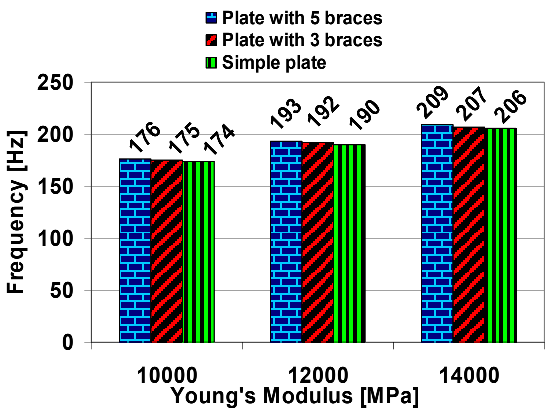
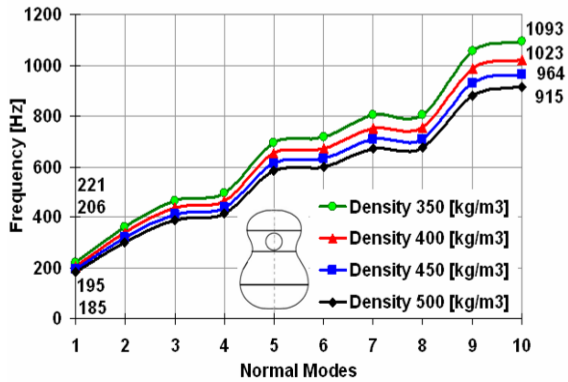


Fig.6. The frequencies' variation of the first mode of vibration in regard to the Young's modulus E

From the Fig. 7. a, b and c it results the following aspects: the fundamental frequency has close values regardless of the plate's structure (the disposal of the stiffening braces); the plates with the density 350 kg/m^3 have the frequencies higher than the ones with the density 500kg/m^3, the difference between the extreme frequencies at first vibration mode is 35 Hz and at mode 10 has a value of 187 Hz. This reflects on the acoustic quality of the musical instruments; a density increasing leads to bigger differences between the superior harmonics frequencies. The low frequency plates have a higher acoustic power, this phenomenon being obtained by using the plates with a high density (450-550 kg/m^3).



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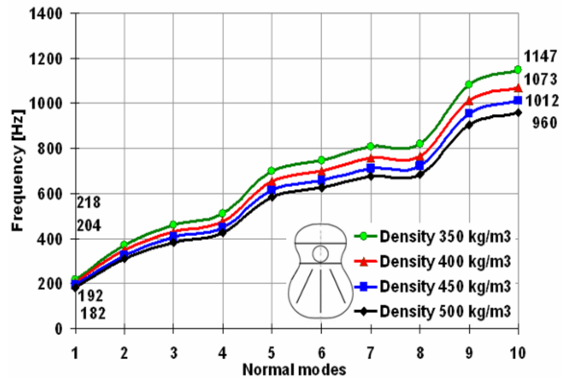
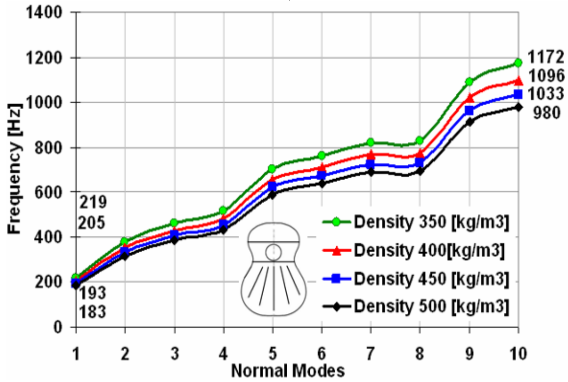


b)



c)

Fig.7. The frequencies' variation for according to the different density ρ

In the Fig. 7. it can be noticed a linear increasing of the frequencies with the plates' thickness: for the same thickness the low density plates (350 kg/m^3) have higher frequencies with almost 20% than the ligno-cellulose composite plates with high densities (500 kg/m^3).

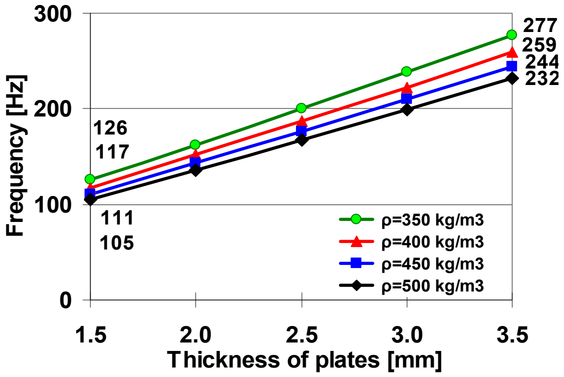
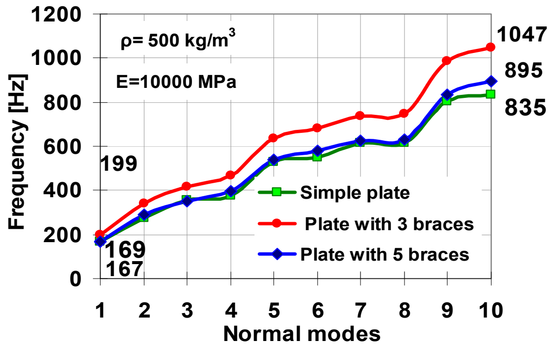
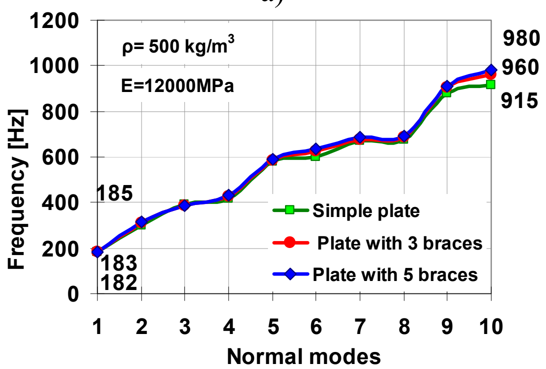


Fig.7. The frequencies' variation for the first normal mode of vibration according to the plate's thickness in the case of the 5 stiffening braces plate and E=10000 MPa



a)



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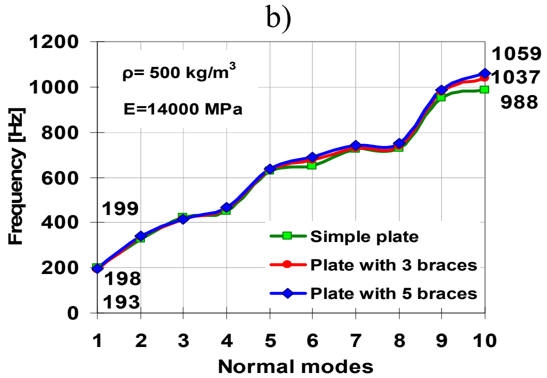

c)

Fig. 9. The frequency's variation according to the modes of vibration for the 3 types of analysed plates with h=2.5 mm and ρ= 500 kg/m^3

In the Fig. 9. a, b and c it can be noticed that the fundamental frequencies' values do not differ too much from one structure to another, for the same density, thickness and elasticity modulus. As the number of harmonics increase, some slight differences appear. Along with the Young's modulus increasing the natural frequencies are no longer influenced by the plate's structure.

3. CONCLUSIONS

The researches made with FEM method on the geometrical models of the different constructive types of acoustic plates as constituents of the classical guitar led to the following conclusions:

-the natural frequencies (eigenfrequencies) and mode shapes (eigenfunctions) obtained trough FEM describe the dynamic properties of the elastic structures of the top plates;

-the shape of the low frequency for different structures of the top plate is similar but with increasing of the overtones the mode shapes become more complex and quite different at the various top plates;

-the natural frequency obtained with FEM range between 167 Hz and 199 Hz which means that is bellow to the fourth octave (132-247.5 Hz) musically speaking; it is necessary to increase this frequency range especially to lower the eigenfrequency because the vibration of the lowest string is 82 Hz.

-the strutting arrangement of the top plates can influence the frequency range of the overtones;

Knowing the normal modes of vibrations and their appropriate frequencies represents a theoretical and a practical importance regarding the resonance phenomenon of the plate and the way in which materials with different properties (elasticity modulus, density, shapes) can be turned to account in musical acoustic. The plates' musical quality influences the acoustic performances of the guitars. This work represents the first step to identify the construction elements (shape, dimensions, arrangement) which influence the dynamic properties. If the materials cannot be change, the geometry and sizes of the top plate can be optimize to bring up the instrument to musical standard.

The real phenomenon of the guitar's vibrations depends on one hand by the eigenfrequency of the plates and on the other hand by the forced vibrations which are generated by strings. The way in which these two types of vibrations are combining will be study in the future work.

4. ACKNOWLEDGEMENT

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