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PARAMETRIC ANALYSIS ON THE LOWER FREQUENCIES OF A ACOUSTIC GUITAR

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Abstract. *This contribution deals with the discussion and definition of optimization parameters of the lowest natural frequencies of an acoustic guitar from the geometric characteristics of the top integrated to their internal bracings. Thus, comparative modal analysis of the top (by using Finite Element Method) was performed to identify the sensitivity to these parameters on the typical lowest frequencies of a guitar. The results provide a primary guideline to beginners' luthiers when tailor manufacturing a customized guitar.*

Keywords: *frequency, optimization, acoustic guitar, Finite Element Method*

1. INTRODUCTION

The art of the acoustic guitar has evolved along the history and its design with it. As it arrived on the guitar that we know today, several innovations have been developed and the complexity to tune it's sound became harder. The inside of the current guitar is full of mechanical bracings as shown in Fig.1, usually build with the same wood as the top to provide more mechanical resistance, besides changing its vibroacoustic quality.

Figure 1.Inside view of the X Bracing in an acoustic guitar.

The current paper has the goal to simplify the acoustic guitar design for beginners' luthiers, giving clear guide paths in which parameters will have greater impact in tuning the lower frequencies for the listener. For that, we proposed a parametric design optimization to vary three different parameters and evaluate how it would impact the first seven modes frequencies of the guitar since low modes have a major impact than other modes as described by Richardson, et al. (2012). According to Meyer (1983), "The lower and middle frequency ranges up to 1000 Hz are the most important.". The parameters to be varied are body thickness, brace height and brace thickness.

2. METHODOLOGY

The acoustic design used as reference was the classic Martin® OM with its famous X bracing, as it was the first iconic sound of the acoustic guitar that lingers until this day. The dynamic model was inspired by the work of Christensen (1980), where the first guitar free body diagram was developed. This model studies the SPL emitted by the system and can predict the decibels.

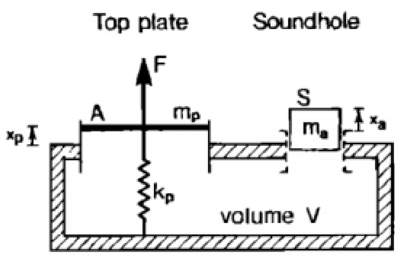

Figure 2. Simplified model for guitar function at low frequencies. This figure is copied from Ove (1980).

The current paper is focused on the mechanical dynamic and will compare the influence of the geometric parameters' variation in the resonance frequencies of the guitar.

From that, this work has analyzed the guitar top and the bracing, considering the sides and the guitar back rigid and therefore having low impact on the guitar frequencies as discussed by Richardson, et al. (2012). The wood behavior was also simplified, being considered isotropic.

The methodology of the work is to calculate 3 rounds of Modal Frequencies analysis so that in each round, one parameter will be fixed as the other two will have its values varied. Thus, to conclude, the parameters degree of influence on the lower frequency modes comparing them.

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3. NUMERICAL MODEL OF THE TOP PLATE AND BRACINGS

The CAD model was created in Solidroks® (Figure X) and was designed to simplify the fillets of the ribs as it has low impact on the results shown by Boven (2017). The CAE model created in Hypermesh® was modeled with 2D Shell Elements instead of 3D, validated by Boven (2017). The boundary conditions of the model was fixing the border of the top in all three translational degrees and all three rotational degrees, as we considered the sides of the guitar rigid in our premisses.

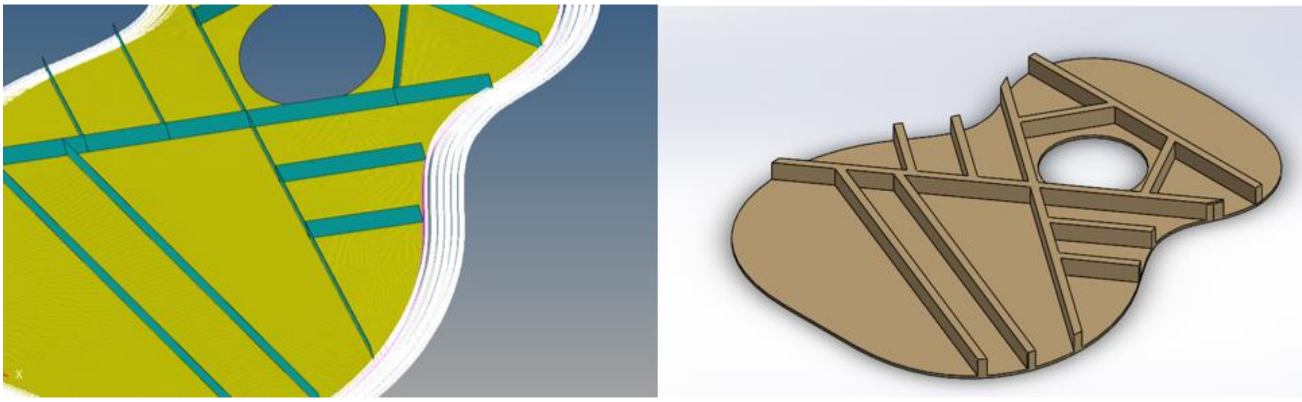

Figure 3. 2D Shell Elements Model and CAD model

The mesh is constructed automatically by the software with a mix of first order square and triangle elements with an average size of 1 mm, totalizing 175623 elements. The processor used had 7 cores with a 1.8 GHz. The average elapsed time of all analysis was four minutes and fifty-three seconds. Our reference guitar model had a 2.8 mm top thickness, 8 mm brace thickness and a 16mm brace height, develop based on Grellier (2007). Figure 4 shows the Element Quality Index and clean up following the recommendations on Practical Aspects of Finite Element Simulation (2015) made to assure the analysis reliability.

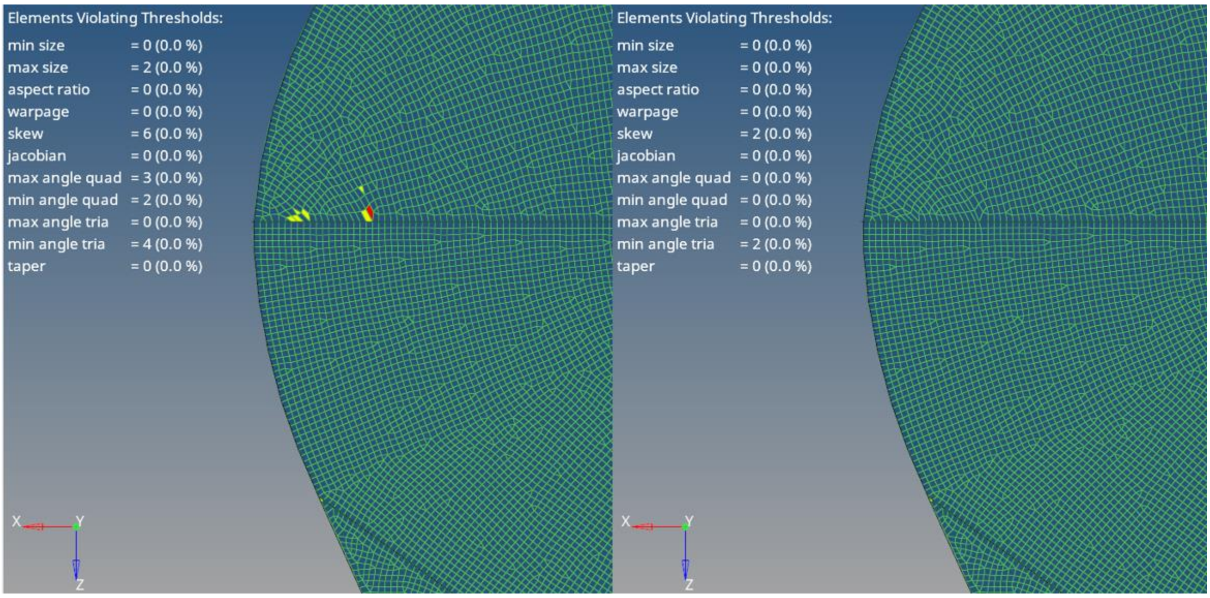

Figure 4. Quality Index in HyperMesh and Element Optimization performed

4. MODAL ANALYSIS AND RESULTS EVALUATION

With the model ready and checked for any mesh issues, the 50 Modal Analysis Subcases were runned to obtain our parametric design variation impact. Figure 5 shows the 7 first shape modes of the acoustic guitar.

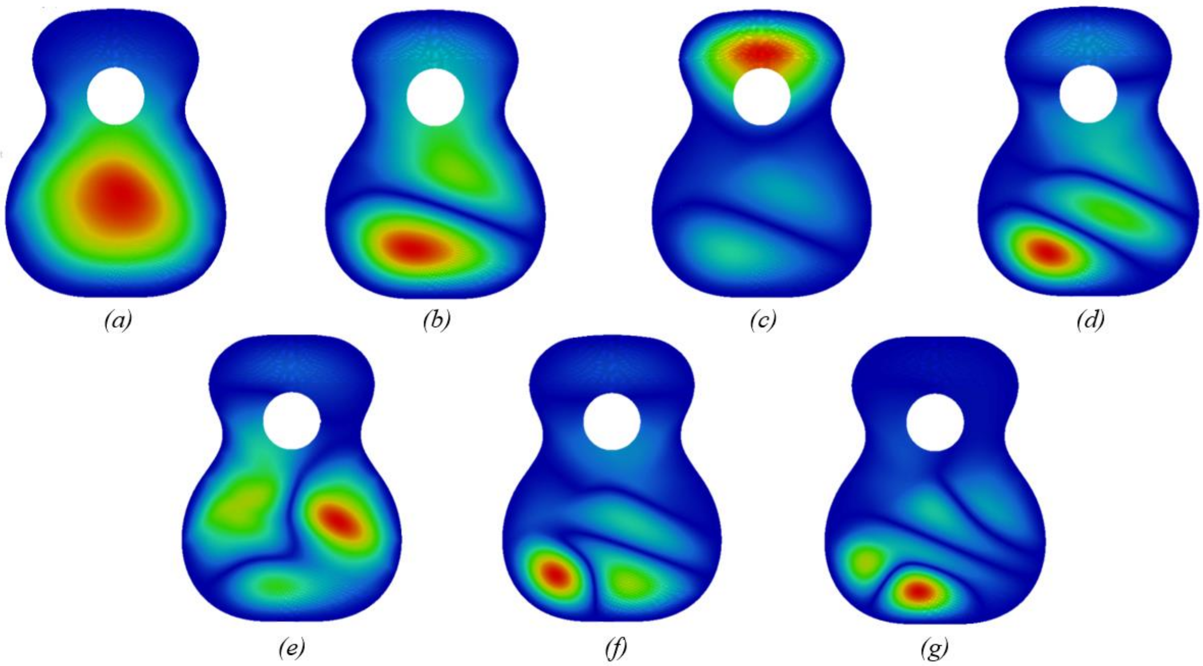

Figure 5. Seven First Modes on the Guitar Top Model

All Analysis Subcases were performed with Optistruct solver using Lanczos method as it has few degrees of freedom and it is a simple model. Thus, from the subcases were obtained the parametric design variation values. Figure 4 shows the 7 first mode shapes of the acoustic guitar to understand the body behavior in low frequencies. To visually evaluate the influence of the parameters 3 graphics were plotted with the Mode Frequency (Hz) in Y axis and the size of each parameter (mm) in X axis, exemplified in the Fig. 5.

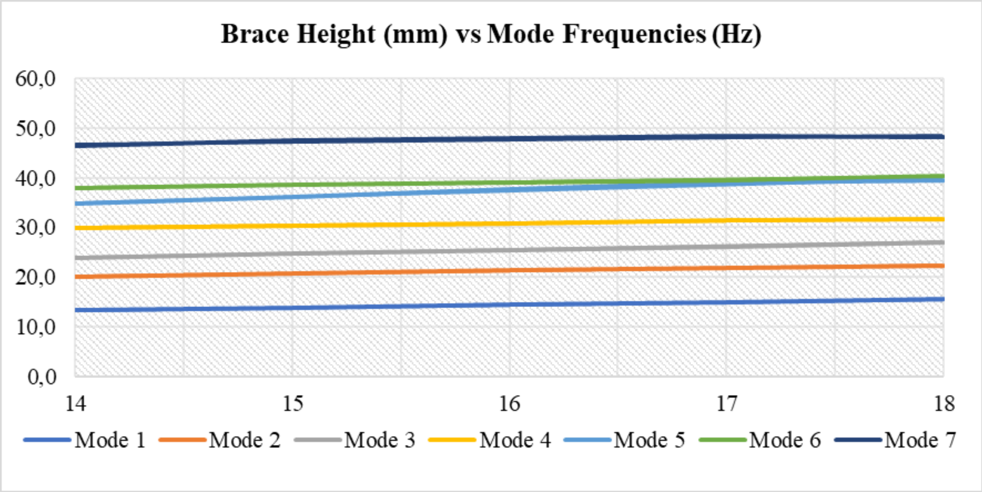

Figure 6. Brace Height vs Mode Frequencies

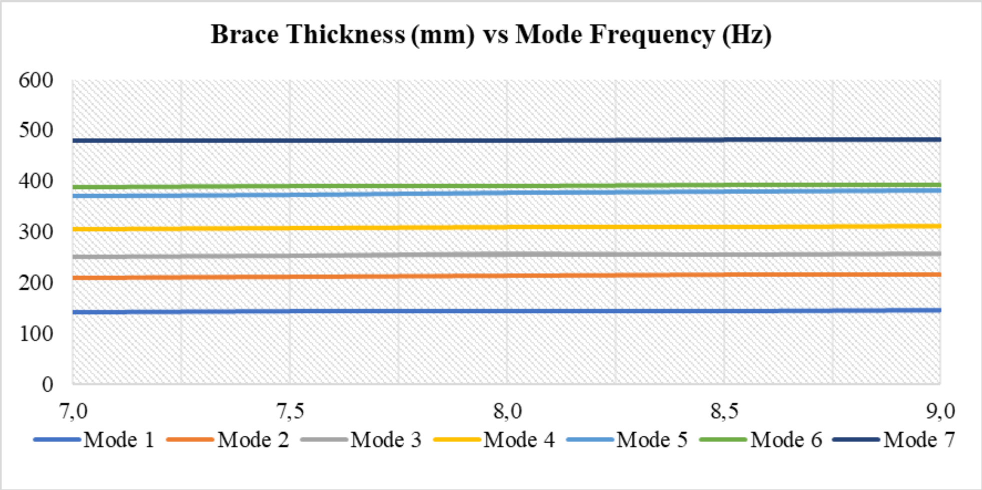

Figure 7. Brace Thickness vs Mode Frequencies

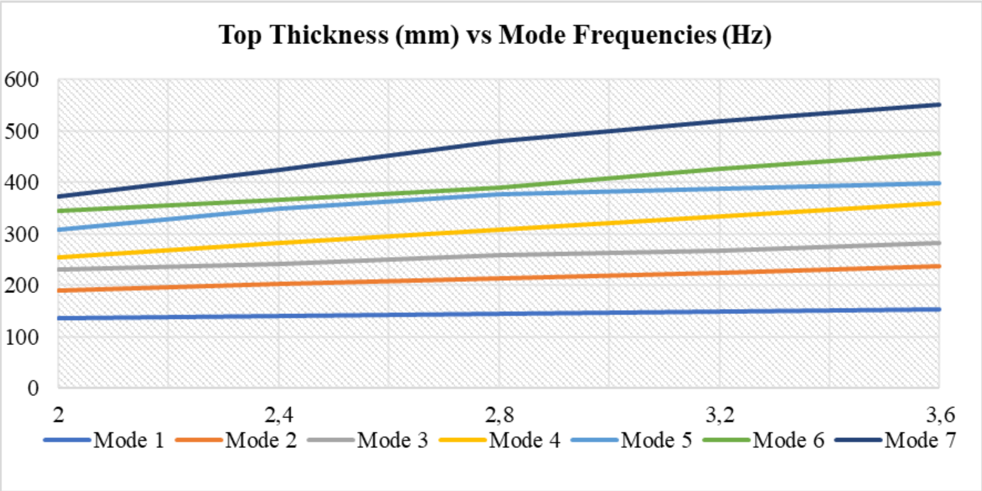

Figure 8. Top Thickness vs Mode Frequencies

To compare more objectively, a linear regression as calculated for each mode curve in the three graphs to create the table with the angle coefficients of the tendency line equation as shown in Tab. 1.

Angular Coefficient			
Mode	**Brace Thickness**	**Brace Height**	**Top Thickness**
1	0,101	0,567	0,409
2	0,182	0,563	1,150
3	0,113	0,787	1,300
4	0,139	0,445	2,604
5	0,294	1,239	2,200
6	0,127	0,579	2,867
7	0,076	0,458	4,509
Average	0,147	0,663	2,148
Std. Deviation	0,073	0,278	1,356

Table 1. Angular Coefficients of Linear Regression for each mode and subcase

5. CONCLUSIONS

Once the evaluation proposed in the beginning of the paper was performed, we concluded that a slight change in the top thickness can have a major influence on the low frequencies of the guitar. The brace height had some impact and can be used for a coarse tuning of the frequencies by luthier, but the main parameter to be adjusted to the taste of the customer and to reach the frequency spectrum that lies inside a musician's head is the top thickness. As a next step, it is proposed to evaluate how the same parameters impact in the sound level pressures of the guitar system, and to develop a acoustic analysis.

6. AKNOLODGMENTS

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7. REFERENCES

[1] B. Richardson, H. Johnson, A. Joslin, I. Perry, The three-mass model for the classical guitar revisited, Société Française d'Acoustique, Acoustics 2012, Nantes, France, 2012.

[2] Jürgen Meyer, Quality aspects of the guitar tone, Royal Swedish Academy of Music No. 38, 1983.

[3] O. Christensen, Bo B. Vistisen, Simple model for low-frequency guitar function, Journal of the Acoustic Society of America, Vol. 68, 1980.

[4] Martijn van Boven, Dynamic response optimization of an acoustic guitar,2017.

[5] Practical Aspects of Finite Element Simulation. A Study Guide Academic Program, Altair, 3rd Edition Released, 2015.

[6] Grellier, 2007. "OM size acoustic guitar". 11 Dec. 2020 < http://www.grellier.fr/en/downloads >.

[7] Richard Mark French, Engineering the guitar, Springer, West Lafayette, Indiana, 2009.

[8] ALVES FILHO, A. Elementos finitos: A base da tecnologia CAE / Análise não linear. São Paulo: Érica, 2012.

5. INFORMATION RESPONSABILITY

The authors are the only responsibles for the information inclued in this paper.