A Study into the Acoustic and Vibrational Effects of Carbon Fiber Reinforced Plastic as a Sole Manufacturing Material for Acoustic Guitars

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Abstract: This study will research a modern design of acoustic guitar by analysis of the vibrational modes. The guitar that will undergo testing has been provided by Emerald Guitars and is solely constructed using Carbon Fiber Reinforced Plastic (CFRP). With the use of COMSOL Multiphysics© the soundboard of the guitar will be simulated and analysis will be carried out to determine the first 10 eigenfrequencies and the modal shapes these create. This paper will detail the preliminary results obtained using the physical data collected through experimental testing in a previous study. The paper will demonstrate an application of the finite element method in the field of musical acoustics.

Keywords: Guitar, Acoustics, Eigen-frequency, CFRP, FEM.

1. Introduction

This paper will detail the use of COMSOL Multiphysics when carrying out an Eigenfrequency analysis on a 3D model of the soundboard of an acoustic guitar constructed solely from Carbon Fiber Reinforced Plastic (CFRP). The guitar has been provided by Alistair Hay of Emerald Guitars, a company based in Ireland who specialise in custom built, high end guitars and who deviate from the traditional inclusion of wood.

Previous work in the area has included the initial investigation of a CFRP plate [1]. This study detailed the physical characteristics of the carbon lay-up used in the manufacturing process through experimental methods. The model of the plate, constructed in COMSOL had, to a high degree of accuracy, an almost identical acoustic response to that which was collected experimentally.

This paper will use the data collected in the initial study to detail the sub-domain settings and will investigate the modal properties on the guitar top plate by means of an Eigenfrequency analysis.

2. Previous Work

The reason as to why only the soundboard of the guitar has been analysed in this manner comes from a study by Caldersmith, G. (1978) [2]. The results of the study found that unlike the violin, the 'back plate of the guitar is not excited at the top plate fundamental resonance to any large fraction of the top plate displacement'. This conclusion was obtained by attaching piezoelectric transducers to both the top and back plates of a guitar.

Further work in the area has also neglected to study the entire guitar body of a guitar [3, 4, 5] and analysis has only been carried out on the soundboard.

This paper therefore as a preliminary study will follow suit and results are presented on the analysis of the soundboard of the guitar.

3. Model Design

A guitar model has been constructed using AutoCAD. The dimensions of the guitar have been obtained by accurately measuring the outside of the body with a set of large 'outside callipers' through a series of points along the edges and across the length and breadth of the guitar body. Complex curves on the body have been measured with the use of a 255mm profile gauge. The model was saved as a .dwg file and imported into Rhinoceros where the CAD model was then split into 3 separate volumes; soundboard, back and sides. The soundboard and back were then extruded by 3mm and the sides were transferred to polylines joined together so to create only one curve and not a series of lines. This was then extruded by 3mm creating a solid object. The solid was then exported as a .stp and .iges file to ensure the 3D compatibility when importing to COMSOL.

Figure 1 below shows the rendered CAD image of the guitar.

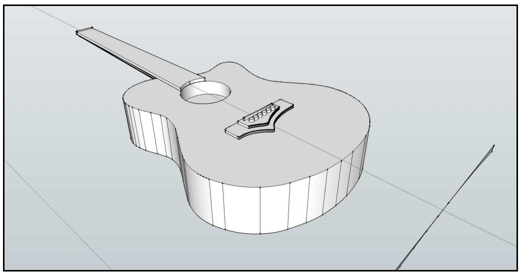

Figure 1: Rendered image of the acoustic guitar from Auto CAD

4. Use of COMSOL Multiphysics

The structural mechanics module in COMSOL 4.2a has been used to carry out an Eigenfrequency analysis on the sound board of the guitar.

4.1 Sub-domain Settings

The physical, material characteristics used in this model are the same as those detailed previously by O'Donnell & McRobbie (2011) [1]. Tables 1 and 2 below detail these for clarification:

Table 1: Material Contents

Variable	Value	Units
Young's Modulus	1.01e9	Pa
Density	1015	Kg/m3
Poisson's Ratio	0.28	

Table 2: Linear Elastic Material Model

Variable	Value
Anisotropic Loss Factor	0.02

4.2 Boundary Settings

As the purpose of this paper is only concerned with the soundboard of the guitar, the boundary settings have been set accordingly. That is, the edges of the soundboard have been fixed in position while only the top and bottom plates of the soundboard are free to vibrate representing a true to life soundboard.

The study has analysed the first 10 Eigen-frequencies of the soundboard and the study settings were 10 desired eigenfrequencies around 100Hz. The relative tolerance of 1.0e-6 has been defined in the general eigenvalue solver configurations and it is felt that this will provide enough detail for this initial study.

5. Results and Discussion

Figure 2 below details the mesh used on the soundboard model

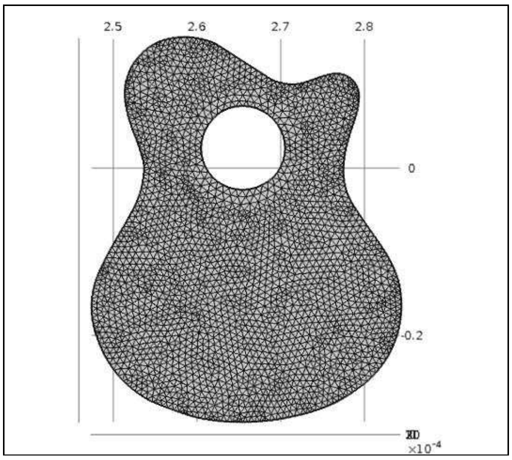

Figure 2: Mesh detail across the sound board of the guitar.

A free tetrahedral mesh was used with a normal element size. The mesh consisted of 14264 elements with a total of 87900 degrees of freedom.

Figures 3 – 5 below are that of the first 3 eigenfrequencies detailed in the solution. The figures represent the 1:1 mode, 1:2 mode and the 2:1 mode respectively.

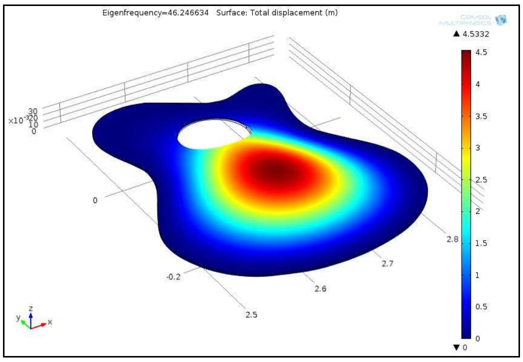

Figure 3: First Eigenfrequency, 1:1 mode.

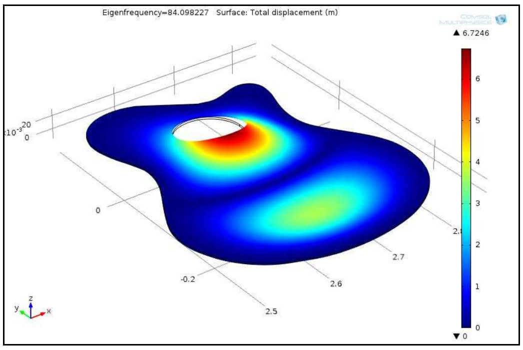

Figure 4: Second Eigenfrequency, 1:2 mode.

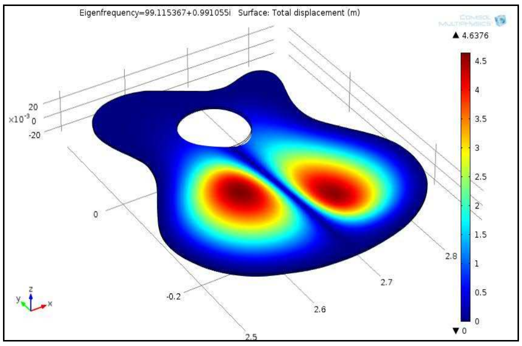

Figure 5: Third Eigenfrequency, 2:1 mode.

When the results are compared to an eigenfrequency analysis carried out on a CFRP rectangular plate of similar dimensions the results are as expected with small discrepancies. Figures 6 - 8 show the first three modes on the CFRP plate.

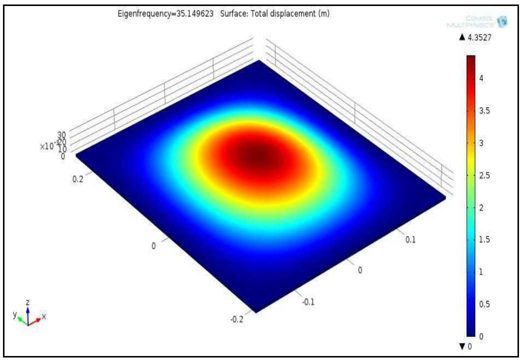

Figure 6: First Plate Eigenfrequency, 1:1 mode.

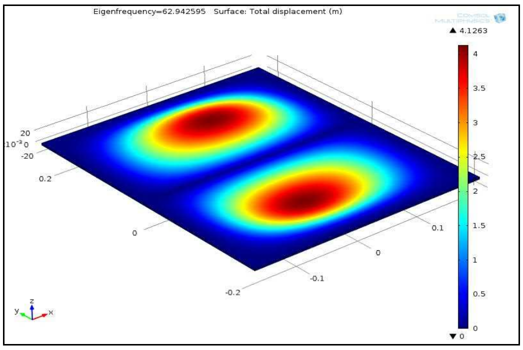

Figure 7: Second Plate Eigenfrequency, 1:2 mode.

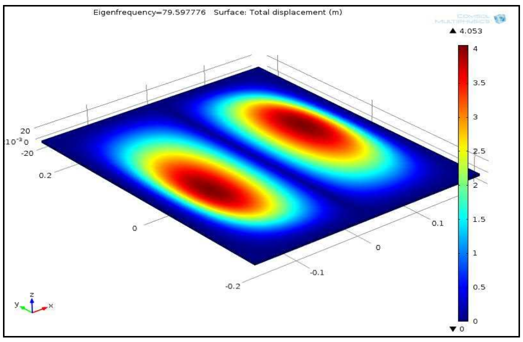

Figure 8: Third Plate Eigenfrequency, 2:1 mode.

The most obvious visual discrepancy is such that the modes have been shifted into the lower bout of the soundboard, simply due to the position of the sound hole. The difference in frequency at which these occur is due to the geometry of the soundboard. However, the results do provide confidence in the model due to the closeness of the resonance frequencies given the differences in the structure.

6. Conclusions and Future Work

While the study has only considered the soundboard of the guitar in this instance, more work will be carried out on the impact of the coupling between the remainder of the guitar body, neck and bridge and the effect these have on the modal properties and frequencies at which these occur.

The results have shown that there is a consistent match between early and current studies for each individual Eigenmode. The data gives the author full confidence to carry out further research in this area and to develop and refine techniques.

Further work in this area will include a study on the effect of the body on the modal shapes and frequencies at which these occur both simulated within COMSOL and with the use of holographic and speckle interferometry.

A detailed frequency response of the guitar will be carried out and analysed compared with simulated data while empirical data of the radiation field of the guitar will be collected these results will be will be presented at a later date.

7. References

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