Analysis of the Mechanical Behavior of Violins Based on a Multi-physics Approach

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Abstract: The paper attempts to give a contribution to the dynamic analysis of musical instruments. A multidisciplinary approach oriented to the study of mechanical, structural, vibratory and acoustical phenomena related to stringed instruments is discussed.

The case study focused in this paper concerns the violins family: the geometry and the vibratory propagation of this instrument is very complicated to study by means classical numerical models. The fluid – structure interactions are very exciting to be focused through multi-physic approaches. The variety of mechanical and physical phenomena concerning bowed musical instruments requires an approach of study integrated between theoretical and experimental procedures and cannot be synthesized in a single paper: hereafter the systematic organization od a multidisciplinary approach proposed by MUSICOS center of research (University of Genoa, Italy) and some preliminary results are presented and discussed.

Keywords: Dynamics, vibration, musical instruments

1. Introduction

The force analysis within a violin is a fundamental topic of interest to correlate vibration and acoustic performance of the instrument. Two different families of mechanical forces must be analyzed: “internal” and “external” forces. “Internal” forces are typically related to the mounting phases of the instrument: classical examples concern the forces generated by the bass bar (Figure 1) glued to the soundboard, by the sound post forced between front and back forces generated between the corner blocks and ribs (Figure 2) and forces generated at the base of the neck. These are structural forces, influencing not only the mechanical features of the instrument but also its stiffness and damping. They can be analyzed, studied and optimized implementing 3D dynamic models.

Forces exchanged between elements not rigidly connected are classified as “external” forces (Figure 3): they are typically generated during the playing phases. The bow in contact on the strings generates forces on the instrument in addition to the static ones. Other forces are exchanged between mobile elements (tuning forces from string to bridge, static and dynamic forces between bridge and soundboard).

Figure 1. Bass bar

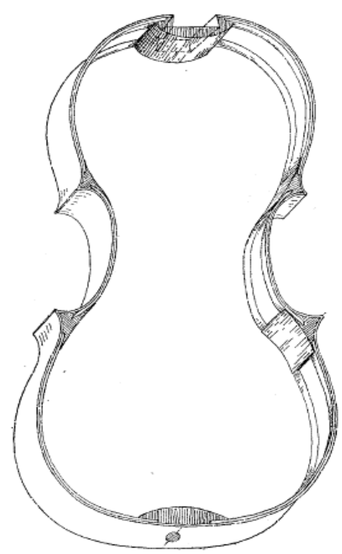

Figure 2. Block corners.

Figure 3: Sites of external forces.

Their theoretical evaluation requires very complicated models and the accuracy of the corresponding result is often not completely acceptable. On the contrary experimental tests are often not taken into account by manufacturers, preferring to estimate the maximum values of the exchanged forces and limit their knowledge to information deduced by empirical references or by simplified tests executable under the instrument assembly. These forces are directly responsible of the vibratory and acoustic performances of the instrument. Their analysis is the subject of a wide research activity at the multidisciplinary Center of Research on Choral and Instrumental Music (MUSICOS) of the University of Genoa (Italy). Theoretical and experimental studies are still under development. Hereafter some specific analyses oriented to evaluate static and dynamic forces into significant point of violins are focused and described.

2. Multidisciplinary approach

The proposed approach of study of stringed instruments is based on different integrated simulation and experimental techniques. Figure 4 shows this approach: In particular structural modification requires data from experimental and numerical modal analyses: here multi-physic codes can strongly support the user. structural and acoustical analyses are interlaced by structural modification procedures and physical analyses.

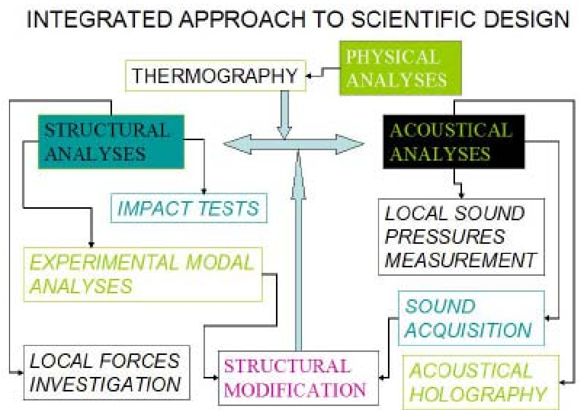

Figure 4: Multidisciplinary approach.

It is opinion of the author that COMSOL multi-physics software can play a significant role within the proposed integrated approach of study. Specific experiences concern, from one side, structural and vibratory analyses of elements of the violin (front, back, bass bar, tailpiece, soundboard, ..) and, from another side, the interaction air-structure defining the acoustic performance of the complete instrument. Some preliminary applications have been successfully implemented and more detailed result will be discussed in the paper.

3. Chladny's figures

A classical method to identify the modal shape of an harmonic plate is based on the definition of Chladny's figures.

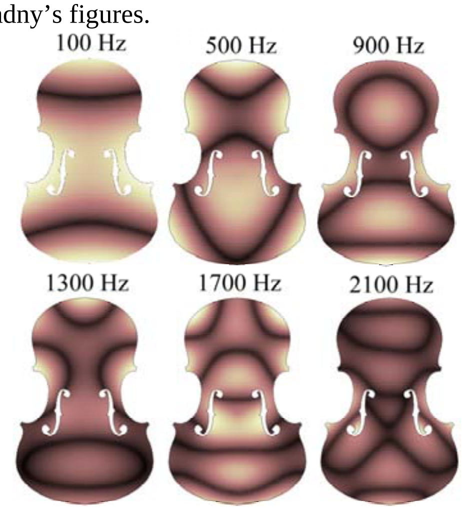

Figure 5: Chladny's figures in the range 100-2100 Hz.

The method, developed also experimentally, consists on the application of a sinusoidal force on a predefined vibrating structure: changing the frequency the mode shapes are detected by an optical approach, searching deformation profiles.
This procedure has been implemented in COMSOL software , after the modeling of an harmonic plate. Some results are collected in Figure 5.

4. Components analysis

About the dynamic analyses of single parts of the violin, good results have been reached on bi-dimensional and three-dimensional models. Hereafter some examples of results are reported: them concern the harmonic plate (Figure 6) and the bridge (Figure 7). This second component is excited by a transversal sinusoidal wave, simulating one of the dynamic effect of a string on the bridge (Figure 8).

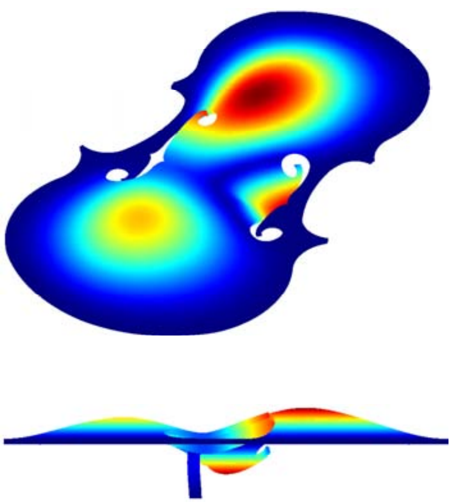

Figure 6: Harmonic plate (2 views)

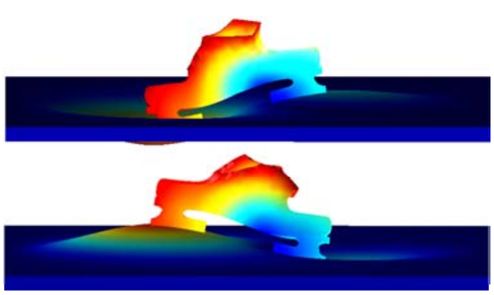

Figure 7: Bridge.

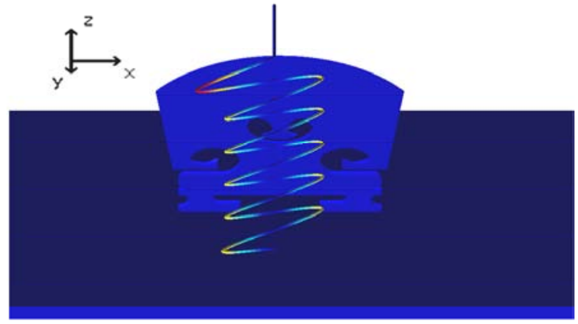

Figure 8: Excitation on the bridge.

5. Complete violin

Starting from the modeling of single elements, a complete geometry of a violin has been performed. Figure 9 show a preliminary result, still under improvement. All fundamental elements are described, but particular shapes of some parts must be detailed, in order to reproduce a real instrument with more fidelity.

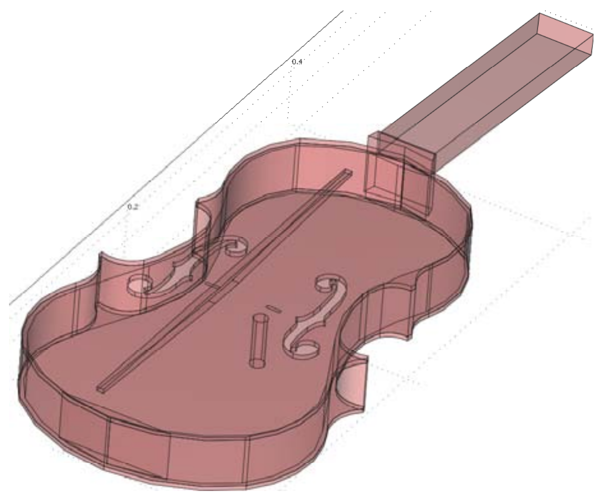

Figure 9: Model of complete violin.

Numerical modal analyses based on this model perform good results: figure 10 collects examples of results at 310 and 510 Hz. External constraints are applied in order to simulate the contact areas between instrument and musician.

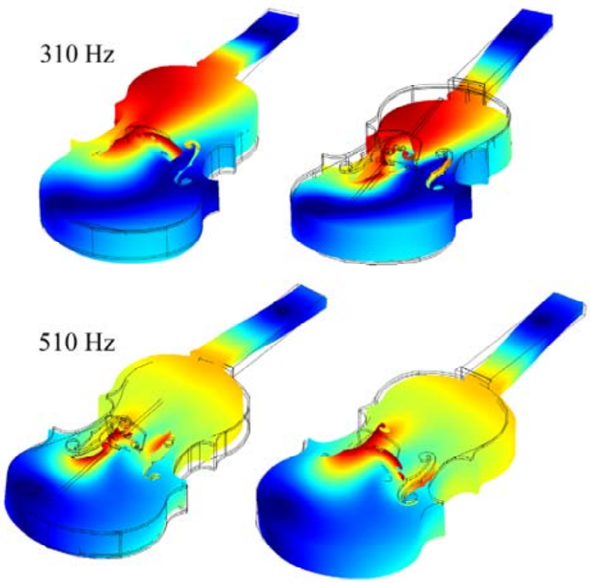

Figure 10: Modal shapes.

6. Acoustic preliminary experiences

Starting from the structural analysis an approach of correlation with acoustic performances has been implemented. The study is still under development and, at the moment, only preliminary results are available. Figure 11 shows the result of an acoustic analysis performed considering the acoustic propagation around the violin. The source is the motion of one string, considered as a vibrating wire.

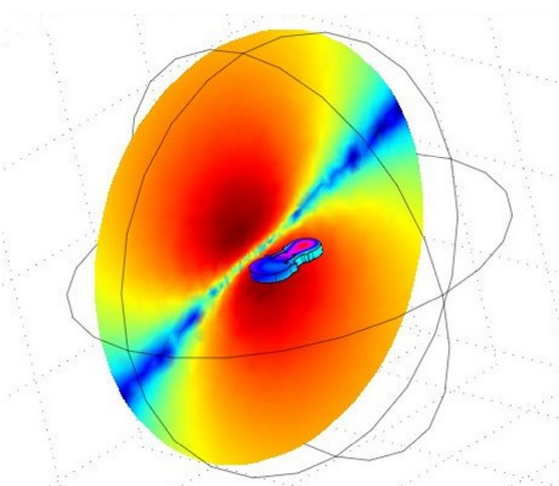

Figure 11: preliminary result of acoustic analysis.

7. Conclusions

Reference models for multi-physic analyses on violins are made available. Further development will be oriented to more detailed approaches, taking into account all the structural and acoustical parameters influencing the performance of the musical instrument.

8. References

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