Numerical models for violins

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Introduction

In the scope of this work a numerical model for violins is presented. Amongst musical instruments the violin for sure is one of the most complex. They are references for high acoustic quality. The long history of violin making and design goes along with a long history of studies on violin acoustics and mechanics. To obtain and understand construction rules for these instruments with the help of engineering methods, it is necessary to describe the acoustic quality with physical parameters and to combine the experience of violin-makers and engineering skills. The physical parameters and their sensitivity to changes in geometry and material properties are achieved with the help of suitable numerical models.

Modeling and Meshing

There exists no ready-to-use geometric description for the complex geometry of a violin corpus. Properties like shape, curvatures and thickness are strongly determined by the luthier's experience and found within an iterative manufacturing process. A geometric description is essential for any kind of physical investigation and numerical simulation. There are several publications in form of mappings of the geometric properties on the 2D contour of the violin. Nevertheless a complete 3D model for the spatial geometry is not available. Within this project a 2D geometric description based on clothoids, described by Sergei Muratov [3] was transformed into a 3D surface model, which consists of trimmed non-rational B-Spline (NURBS) surfaces, from which a volumetric solid shell mesh for the FEM computation was obtained using the meshing code Visual DoMesh [1] (Chair CiE, TU München). The overall workflow from the initial contour to the solid shell mesh is depicted in figure 1.

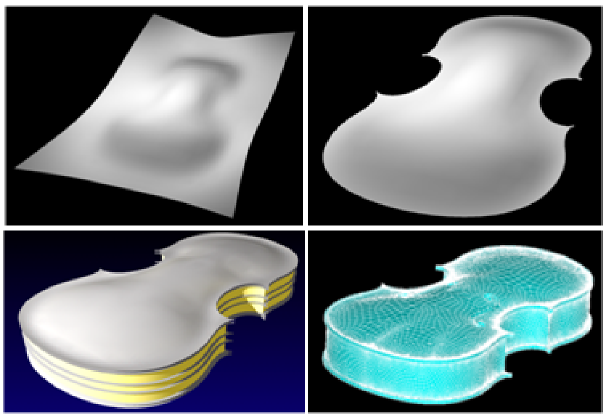

Figure 1: Modeling and meshing workflow

Numerical Analysis of the Violin

The basis for a numerical simulation is a suitable but rather simple digital model to represent the dynamic and physical behavior, which contains only the necessary details and parts of a violin.

Bass bar, sound post and F-holes: Strong influence on stiffness and asymmetric vibration pattern of top and back plate as well as fluid-solid-interaction.
Bridge: Transformation of excitation force from the strings to the corpus.

The tone of a violin is initiated by the bowing (not within the scope if this project) and mainly radiated from the violin corpus. To obtain isolated parameters for the multiple physical effects, the violin was divided in subsystems, sketched in figure 2.

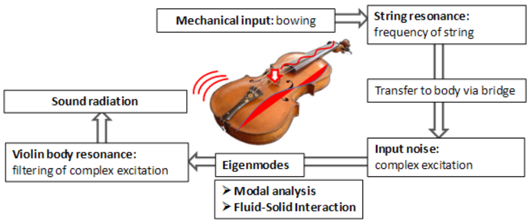

Figure 2: Interaction of physical effects and subsystems

Modal Analysis

Modal analysis is a central technique to investigate the dynamic behavior of a structure. The general form of the equation of motion is turned into an eigenvalue problem.

$$[\mathbf{M}]\{\mathbf{x}''\} + [\mathbf{C}]\{\mathbf{x}'\} + [\mathbf{K}]\{\mathbf{x}\} \quad = \quad \{\mathbf{0}\} \qquad (1)$$

The damping matrix [C] is neglected here. The natural frequencies and mode shapes are obtained from simplified orthotropic FE-models shown in figure 3.

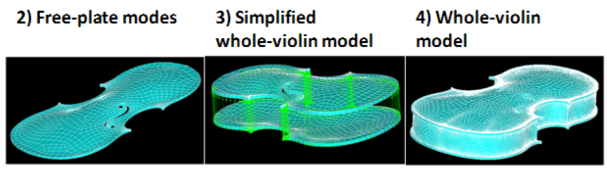

Figure 3: Models for numerical modal analysis

Free-Plate Modes of Curved Shell

Free-plate modes without boundary conditions applied show the contribution of the plates to the vibration patterns of the whole corpus. The results obtained within this project are shown in figure 4. They are qualitatively comparable to experimental results for example published in [2].

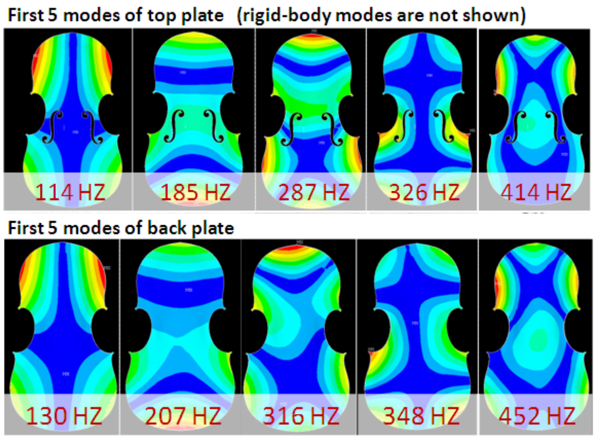

Figure 4: First 5 free-plate modes of top and back plate

Free-Plate Modes of Flat Shell and Modifications

Within this project a simple corpus model was built to investigate the influence of geometric modifications on the eigen-frequencies and -shapes. Whereas some modifications (e.g. thickness) change all modes in a similar direction, others change the ratios between them and therefore may have big influence on the harmonics.

Whole Violin Analysis

The modes and natural frequencies of the whole corpus where obtained from a simplified whole-violin model, where the sidewalls are replaced by DOF-coupling and a complete whole violin model. In principal also the simplified model is able to represent the physical behavior, if the stiffness on the boundary is adjusted. The applied boundary conditions are similar to those of experimental setups. The results of the whole model are presented in figure 5. They are a basis for further optimization processes.

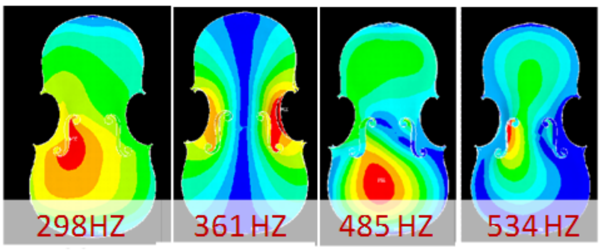

Figure 5: First 4 whole-violin modes

Fluid-Solid Interaction

The Helmholtz-frequency is obtained out of a harmonic FSI-Analysis for a simplified corpus model. Figure 6 shows the Helmholtz mode at 280 Hz with its sound pressure distribution. The peak in the sound pressure level is detectable in the plot of pressure versus frequency.

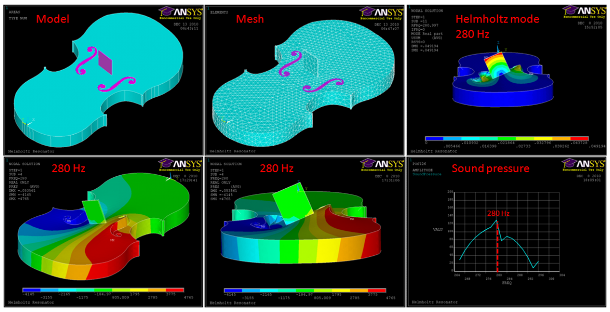

Figure 6: Helmholtz mode and sound pressure level for a simplified corpus model

Sound Radiation

The spectrum of the radiated sound power for a unit load is calculated with a Boundary Element Model, using the velocities from a harmonic FE-Analysis as boundary conditions. The influences of several design changes on the sound radiation were investigated in this project.

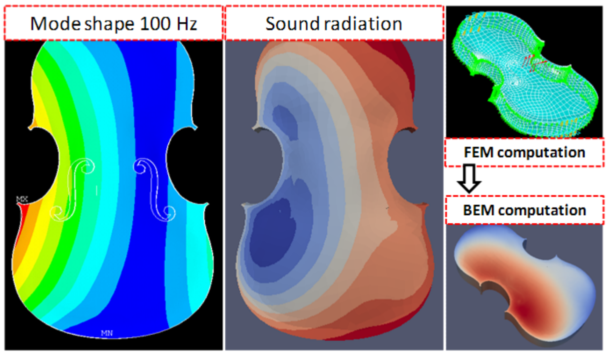

Figure 7: Mode shape and sound radiation

Outlook

It was shown, that by the workflow sketched in figure 2, the acoustical properties of a certain geometry can be estimated. In a next step this workflow shall be automized in order to enable a fast sensitivity analysis on geometric changes without further user interaction (steering).

References

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