Vibro-Acoustics of Violins based on a Multi-Physic Approach

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Abstract: The paper attempts to give a contribution to the dynamic analysis of musical instruments through application of a multidisciplinary approach oriented to the study of mechanical, structural, vibratory and acoustical phenomena. The systematic organization of the multidisciplinary study proposed by MUSICOS and some preliminary results related to bowed instruments, with particular reference to violins, are discussed.

Key-Words: Vibration, Acoustics, Dynamics, Musical Instruments, Violins, Multi-physics, Modeling.

1 Introduction

Acoustic musical instruments address various, significant and interlaced mechanical and physical phenomena. Stringed and bowed instruments show interesting peculiarities: the geometry and the vibratory propagation of instruments belonging to these families are very complicated to study by means classical numerical models. From one side the fluid-structure interactions are very exciting to be focused through multi-physic approaches and, from another side, dynamic, vibratory and mechanical features strongly influence the acoustic performance and the sound propagation.

The systematic organization of multidisciplinary theoretical and experimental approaches of design and testing of musical instruments is proposed by MUSICOS Centre of research of the University of Genoa (Italy), following the logic synthesized in Fig. 1.

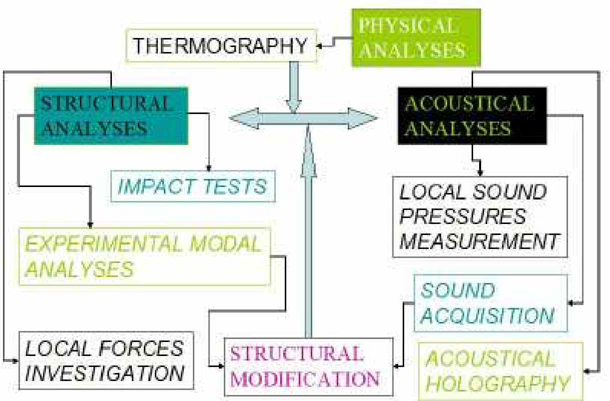

Fig. 1: Integrated approach to scientific design

Structural investigations involve, in particular, numerical and experimental modal analyses both of single parts and the whole instrument. The dynamic response under forcing functions require the detection of local forces exchanged in specific contact area. In the case of violins the monitoring of the actual force generated in the contact between bridge and soundboard is very important. It is consequence to played strings and must take into account the external mechanical constraints imposed to the instrument by the musician.

Acoustical investigations involve local sound pressures measurements, sound acquisition and acoustic holography in the space around the instrument.

Fitting of structural and acoustical analyses suggests structural modification approaches: further physical investigations (i.e. concerning the environment or the thermal behaviour of the instrument under test) complete the integrated approach.

2 Problem Formulation

The violins family is particularly suitable to apply the proposed multidisciplinary approach.

Different modeling and simulation codes are involved and simulated results are compared to experimental tests implemented on specific instruments.

The approach based on COMSOL multi-physics software is, in particular, discussed. It plays a significant role within the proposed integrated approach of study. Specific experiences concern, from one side, the structural and vibratory modelling of elements of the violin (front, back, bass bar, tailpiece and soundboard) and, from another side, the interaction air-structure defining the acoustic performance of the whole instrument. Some preliminary models have been successfully implemented and the corresponding results are discussed hereafter.

3 Problem Solution

The force analysis inside a violin is a fundamental topic of interest to correlate vibration and acoustic performances 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, glued under the soundboard, by the sound post forced between soundboard and back, induced between the corner blocks and ribs (Fig. 1) 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 have been analyzed, studied and optimized implementing 3D dynamic models.

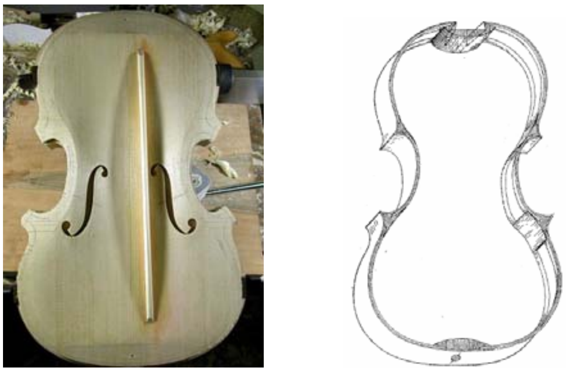

Fig. 2: Places of "internal" forces.

Forces exchanged between elements not rigidly interconnected are classified as "external" forces: 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 (Fig. 3). Other forces are exchanged between mobile elements (tuning forces from string to bridge, static and dynamic forces between bridge and soundboard). Their static and dynamic theoretical evaluation requires very complicated models and the accuracy of the corresponding results 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 during the instrument assembly phases.

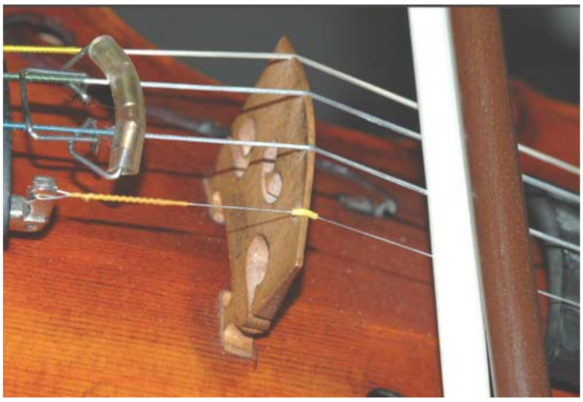

Fig. 3: Places of "external" forces.

4 Mechanical and Structural Models

First step of the multi-physic analysis concerns the implementation of geometrical and dynamic models of single parts of the violin, describing the mutual actions generated under simulated vibrations of the strings.
Original bi-dimensional and three-dimensional have been implemented: some examples of results, concerning the harmonic plate and the bridge, are synthetically described.

4.1 Bridge

As well known, the bridge is the interface between strings and soundboard: its role is fundamental for the vibration propagation and has been studied in detail by various researchers. A 3D model of a classical bridge is defined: the action of the string has been simulated considering the actual motion of the bow on the string, in particular taking into account vibrations tilted with respect to x-y plane (Fig. 4).

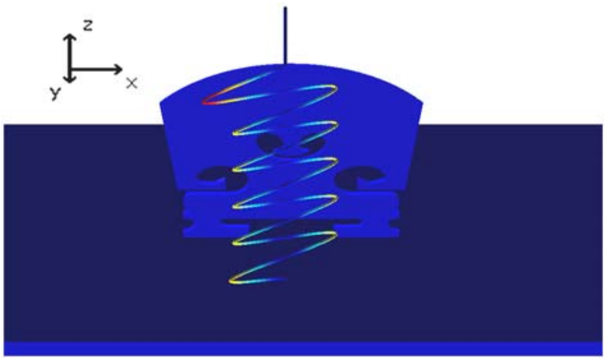

Fig. 4: Excitation on the bridge.

The consequent motion of the bridge is shown in Fig. 5. Two images make evident the effect of fulcrum generated by one of the two feet: this effect is magnified by the sound post, able to increase the stiffness under the feet.

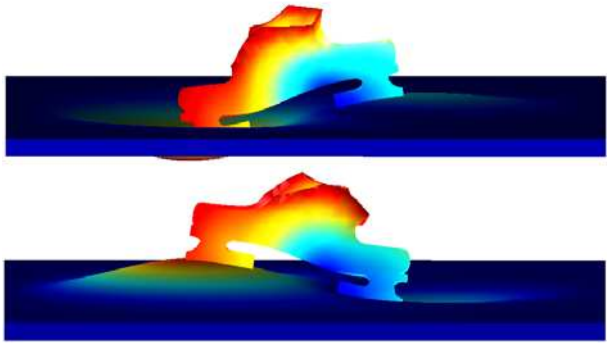

Fig. 5: Dynamics of the bridge.

4.2 Soundboard
In order to detect the level of accuracy of the dynamic analyses based on COMSOL code, and before to model more complicated structures the classical approach identifying the modal shape of an harmonic plate based on the definition of Chladny's figures, has been simulated (Fig. 6). 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.

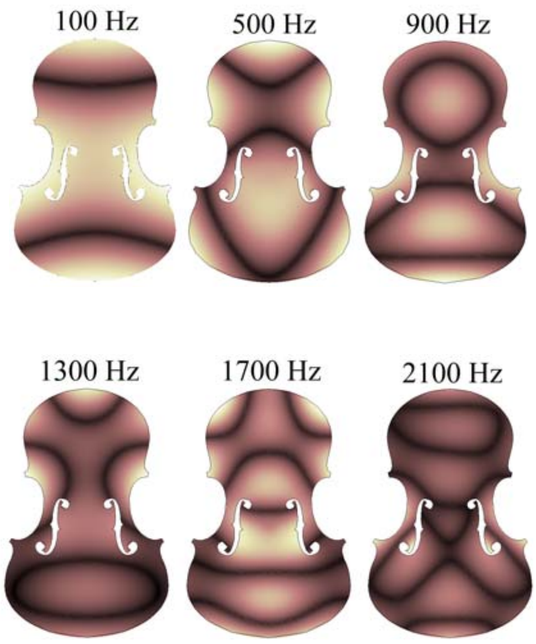

Fig.6: Chladny's figures (100-2100 Hz range).

The good results of this test have supported the soundboard modeling, Bass bar and sound post are considered. The bass bar is pre-deformed and glued to the harmonic plate. The sound post is forced between soundboard and back and generates a static deformation of these surfaces.
The effect of the modeling in shown in Fig. 7.

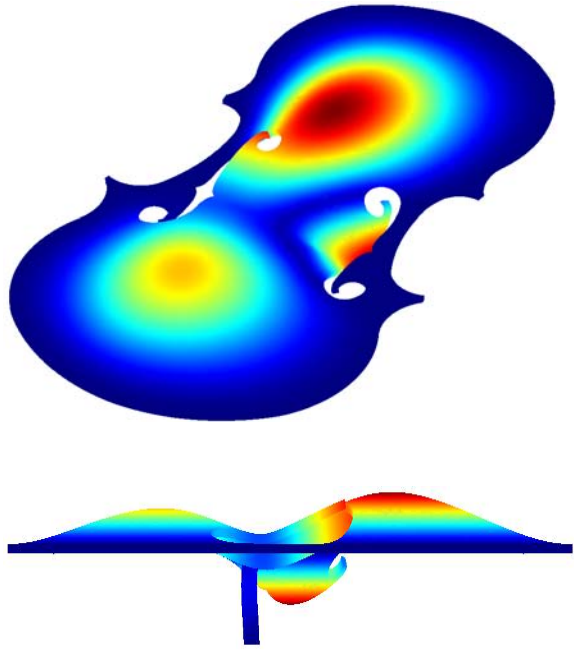

Fig. 7: Soundboard modeling (2 views).

4.3 Complete violin
Starting from the modeling of single elements, the whole geometry of the violin has been performed. Fig. 8 shows a preliminary result: improvements are, at the moment, in progress. All fundamental elements are described, assembling the previously described elementary models in order to reproduce a real instrument with more fidelity.

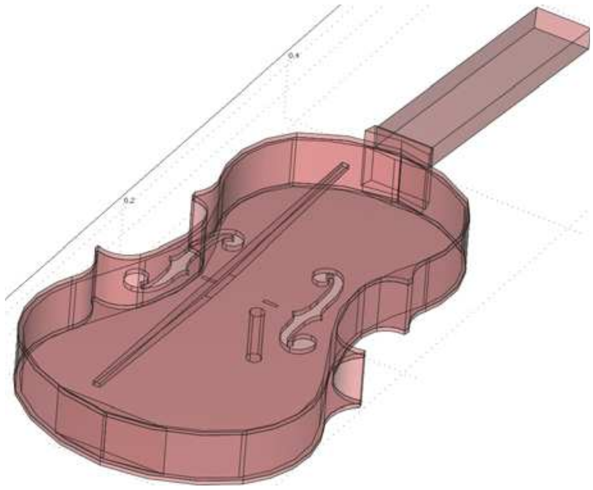

Fig. 8: Model of the whole violin.

Numerical modal analyses based on this model perform good results: Fig. 9 collects examples of results at 310 and 510 Hz. External constraints are applied in order to simulate the contact areas between instrument and musician.

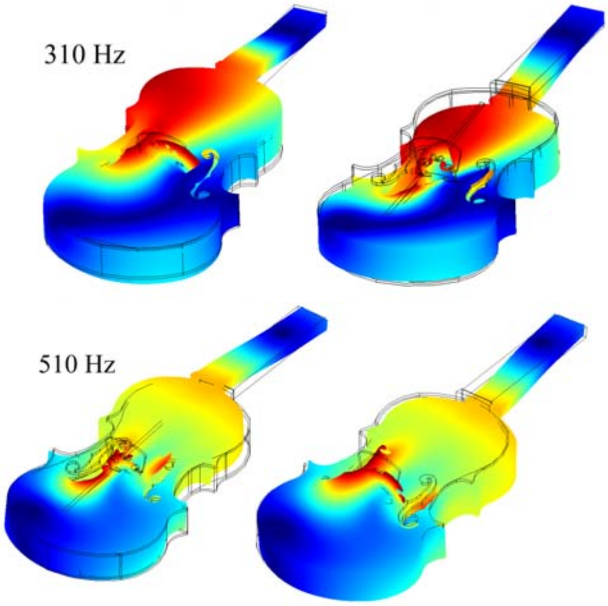

Fig. 9: Modal shapes.

4.4 Acoustic preliminary experiences

Starting from the structural analysis an approach of correlation with acoustic performances has been implemented. The source is the motion of one string, considered as a vibrating wire. The mechanical action is generated on the body of the violin through the feet of the bridge: acoustic pressure as function of the frequency (related to the sound propagation in air) is modeled and applied in correspondence of the contact areas of the bridge feet (Fig. 10).

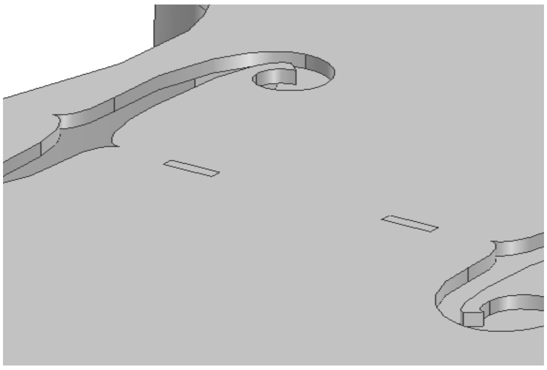

Fig. 10: Detail of the contact areas between feet and soundboard.

Then, properties related to materials can be modified: in particular density, Young's modulus and Poisson coefficients. Models of fluid-structure interaction proposed in literature are implemented into the code. Fig. 11 shows the result of an acoustic analysis performed considering the acoustic propagation around the violin.

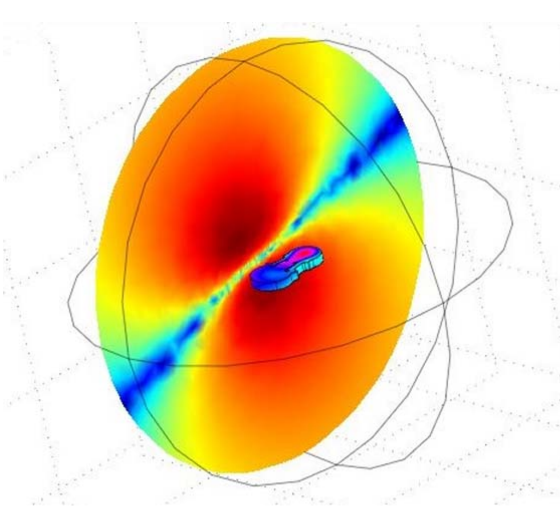

Fig. 11: Acoustic analysis.

5 Conclusions

A multi-physic model based on structural and acoustical parameters influencing the performance of a violin has been implemented. It can be applied to analyse other stringed and bowed musical instruments. Further development will be oriented to improve more detailed models, with particular reference to fluid-structure interaction.

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