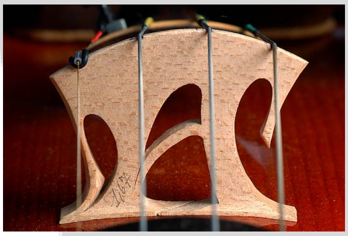
## P 15 Modeling, identification, and optimization of violin bridges (W. Ring, B. Wohlmuth) $\rightarrow$ AO, NS, IS

**State of the art.** Starting with the monochord of the ancient greeks, the mathematical study of musical instruments one of the oldest topic in applied mathematics. Within the last century, the field has vastly expanded (see e.g. [7, 9, 13] and the references therein), with the availability of realistic continuum mechanical descriptions and powerful signal processing tools. Finite element based approaches are much less often pursued due to the complex geometry of typical (parts of) instruments, the inhomogeneous and often highly anisotropic material properties, the necessity to resolve high frequencies and the difficulty of formulating suitable mathematical quality criteria which might make it worthwhile to set up a quantitatively accurate model. However, FEM models have been used for violin simulation (see e.g. [3, 10]) and even optimization and identification [5]. Violin bridges have been studied under various perspectives: Filter properties [12, 1], FEM Simulation [15], topology optimization [14] and active control [2].



**Thesis project to be supervised by Wolfgang Ring.** The bridge in a violin is the slender piece of maple over which the strings run and which transfers the vibration from the string to the body of the instrument.The energy enters the bridge at the top edge as a periodic excitation and leaves at the two feet thus setting the top plate of the violin in motion. Since the bowed string vibrates almost exclusively within a plane due to the contact with the bow, the excitation is a tangential periodic force located at one of the four groves at the upper edge. The top plate acts as a membrane which radiates acoustic energy into the surrounding space. To do so, it is excited by a periodic transversal force at the contact points with feet of the bridge. The input-output relation is highly influenced by the dynamic behavior of the bridge. In the excited state, the weaker middle part underneath the heart yields spring-like under the influence of the external forces and the larger amount of wood in the upper part acts as an inert mass in a vibrating system. Obviously, the distribution of eigenvalues and the damping coefficients of the bridge as an elastic system will have a considerable influence on the tonal properties of the instrument. From a signal processing point of view, the bridge acts as a linear filter which takes up the input signal from the string and produces two modified output signals at the feet [1]. The identification and control of the corresponding frequency response function are one main goal of the proposed project. It has been observed and theoretically justified that a so called *bridge hill* occurs in the response function around 2500 Hz in high quality violins (see [12]). Especially the estimation of parameter configurations leading to a prominent bridge hill will be studied.

The filter properties of the bridge are influenced by a variety of parameters. Apart from material parameters, the geometric design is utmost importance. Although the general shape elements (heart, ears, feet) of a classical violin bridge are rather universal, their sizes and placement vary considerably between different makers. The dominant opinion seems to be that the width of the waist and the distance from the heart to the upper edge are essential parameters which should be kept within certain limits. In the project the sensitivity of the bridge with respect to variations of these parameters will be investigated and analyzed.

Recently more radical bridge designs (see above picture) were promoted mainly with the motivation to guarantee a well balanced behavior of the bridge with respect to input from different strings. We plan to compare the new design to the classical one with respect to this alleged merit and aim for the optimization of design parameters within the classical setting to achieve an optimally balanced bridge.

The bridge will be modeled as linear elastic, orthotropic structure [11] using isogeometric analysis [6, 8] together with high order finite elements and local refinement strategies ($p$ or $hp$ elements). In the first stage the bridge will be modeled by clamping the feet tangentially to the surface of the top and modeling the coupling with the top plate by a simple mass-spring system (see [12]). In order to perform sensitivity studies and run sensitivity based optimization routines using adjoint variable techniques, we need to be able to have access to derivatives of the FE matrices with respect to design parameters. This in particular excludes the usage of existing multiphysics software.

**Further topics.** A real violin is assembled from various different parts an nearly all of them are important for the overall performance. As a second step a partial FE model of the top plate shall replace the mass-spring system using isogeometric mortar elements [4] to describe the coupling.

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