Acoustics'08
Paris
June 29-July 4, 2008
www.acoustics08-paris.org

Performance comparison of violins through experimental force analyses

Enrico Ravina[a], Paolo Silvestri[b] and Federico Lowenberger[c]

[a]University of Genoa - Centre of Research on Choral and Instrumental Music (MUSICOS),
Via Opera Pia 15 A, 16145 Genova, Italy
[b]Univ. of Genoa - DIMEC, Via Opera Pia 15 A, 16145 Genova, Italy
[c]Master Violinmaker, Via Marussig 13, 16100 Genova, Italy
enrico.ravina@unige.it

The paper describes the most recent experiments developed on violins with different mounting (baroque, classical, modern) and specifically oriented to the dynamic forces analysis in significant points of the instruments. The vibratory behaviour of the soundboards is strongly influenced by the dynamic forces transmitted from the bridge: they are related also to the tension of the strings. An original test bench conceived to forces measurement has been set up: tensions on strings, forces detected under the bridge and deformations on the fingerboard and on the tailpiece are, in particular, monitored by means not intrusive thin-film tactile pressure measurement devices, micro-load cells and micro-strain gauges. Mapping of forces and strains can be acquired in real time playing the instrument; the paper reports comparisons between differently mounted violins, playing notes under different techniques: continuous (“tenuta”), ghost (“strappata”), … Experiments are developed using different kind of strings (bowels, metallic,...). The results are used as inputs for experimental dynamic analyses and tests of the soundboard: in addition, they can be correlated to the acoustic response of the instrument.

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 can 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 sound post (Fig.1) glued to the soundboard, by the bass bar forced between front and back (Fig 2, source [1]), forces generated between the corner blocks and ribs (Fig 3, source [1]) and forces generated at the base of the neck (Fig. 4).

Fig. 1: Sound posts.

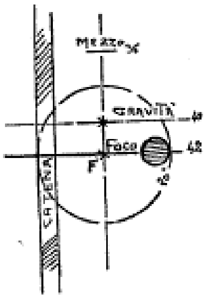

Fig. 2: Bass bar.

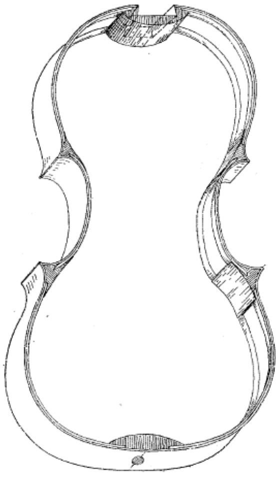

Fig. 3: Corner blocks.

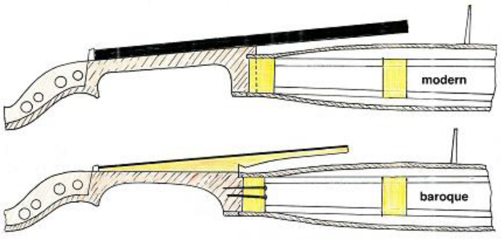

Fig. 4: Neck connections.

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: 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). 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. A typical case is the evaluation of the actual forces generated by strings on the bridge (Fig 5, source [1]).

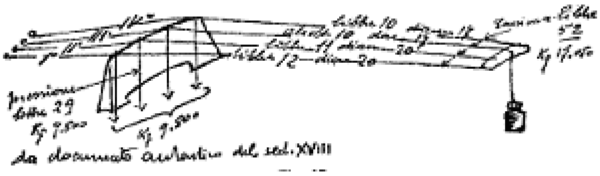

Fig 5: Empirical tests of string forces.

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 Centre 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.

3 Numerical models

The evaluation of "internal" forces is very difficult to perform through experimental tests. Solutions based on micro-sensor embedded into the instrument and integrated during the phases of construction are under study but, at the moment, the approach is complicated to realize without a modification of the actual dynamic behaviour of the instrument. In fact the installation of internal sensors is often difficult to be performed, in particular for the nature of the materials and for the local geometries. For this reason analyses on internal forces are preferably developed using numerical models: finite element methods procedures are applied to study single elements and their static and dynamic interaction in the complete instrument. Figs. 6 and 7 show phases of 3D analyses on corner blocks and on sound post under development at the MUSICOS centre of research.

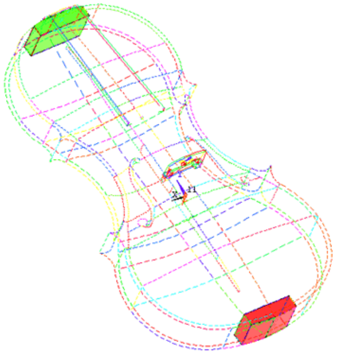

Fig. 6: Analysis of corner blocks.

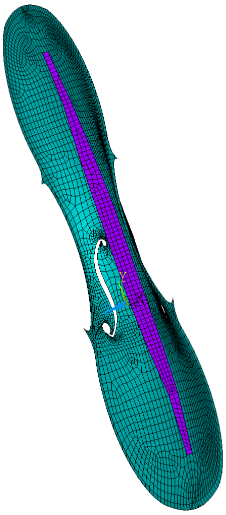

Fig. 7: Analysis of sound post.

Analyses are implemented using ANSYS code, with original customizations on the definition of the mechanical and structural characteristics of the materials. A detailed presentation of the result of this numerical approach will be reported in a next paper.

4 Experimental approach

The evaluation of the "external" forces and of the mutual forces exchanged between components (also with possible relative motion) is performed by experimental methods. The basic idea is to develop a measurement chain easy to be reproduced, at low cost, in different environmental conditions, minimizing the intrusion of sensors and able to detect forces in specific points of the instrument also during the playing phases.

Some main zones interesting for the experimental detection of local forces, strains and stresses have been focused:

- bounds of strings on the tailpiece and on the pegs;
- contacts of strings on the nut ;
- upper and lower contact areas of the bridge (string-bridge and bridge-soundboard interactions);
- deformations on the fingerboard and on the tailpiece.

4.1 Strings

As well known the bridge supports the load generated by the strings and its relative position with the soundboard and the nut defines the vibrating length of the strings. Through the bridge string vibrations reach the soundboard: its mechanical behaviour is one of the fundamental factors for a good sound performance of the instruments (Fig. 8).

Fig. 8: Interaction strings-bridge.

The strings have equal length but different diameter: then their tension is different, in static and dynamic conditions. The string material is another element to be considered: bowels, metallic ropes and various solutions are today available on the market.

The overall static tension (tuning tension) of strings is estimated around 250 N on modern violins: empirical tests [1] estimate tensions of 170,5 N on baroque violins (Fig 1). But these values are only indicative and little variations produce significant effects: a little variation on the string diameter or a different inclination of the neck strongly modifies the actual values of the forces induced on the strings.

The proposed experimental approach detects the tension of strings using four micro load cells, mounted in parallel. Cylindrical cells (diameter 39 mm, thick 5 mm) are used:

each cell is equipped with screw metallic terminals and the group of cells can be easily mounted between strings and tail piece or between strings and pegs.

4.2 Bridge

The mechanical structure of the bridge must be able to support maximum forces without deformations. Its geometry changes with the evolution of the violin (baroque, classic, modern): Fig. 9 shows this evolution aspect.

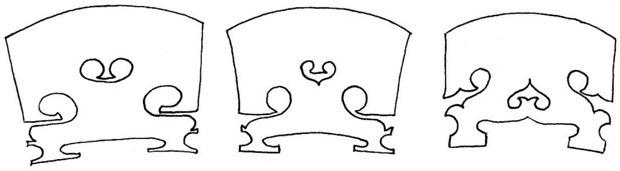

Fig. 9: Baroque, classic and modern bridges.

The corresponding theoretical force on the bridge is estimated on 120 N; empirical tests estimate forces of 98 N. The importance of the bridge shape and dimensions is proved by a wide theoretical studies developed by different authors in various periods.

4.3 Fingerboard and tailpiece

These structural elements have modified geometries on baroque, classic and modern violins. Fingerboard follows the geometry of the neck (Fig. 10).

Fig. 10: Neck and fingerboard.

The measurement chain proposed involves not intrusive thin-film tactile pressure measurement devices, micro load cells and micro strain gauges. Indirect measurement of dynamic phenomena is performed by an infrared thermo-camera. All the transducers are managed by means a portable personal computer.

5 Experimental setup

The preliminary analysis on the forces has been performed starting from the bridge: a micro load cell is located under a bridge and its signal is monitored in real time (Fig. 11).

Fig. 11: Micro load cell under the bridge.

The influence of different kinds of bridges and of different tilt angles of the string, characteristic for modern and baroque mounting, is in particular analyzed. To avoid variations of the tilt angle of the strings (due to the thickness of the transducer) an adjustable bridge is used. The violin is played with different musical techniques: in particular continuous notes ("tenute") and ghost notes ("strappate"). Hereafter a comparison of results is reported: Fig. 12 (a, b) collects the response of the same modern violin equipped by bowels and metallic strings and played on D4 continuous note. Load cell output voltage vs. time is reported:

a)

b)

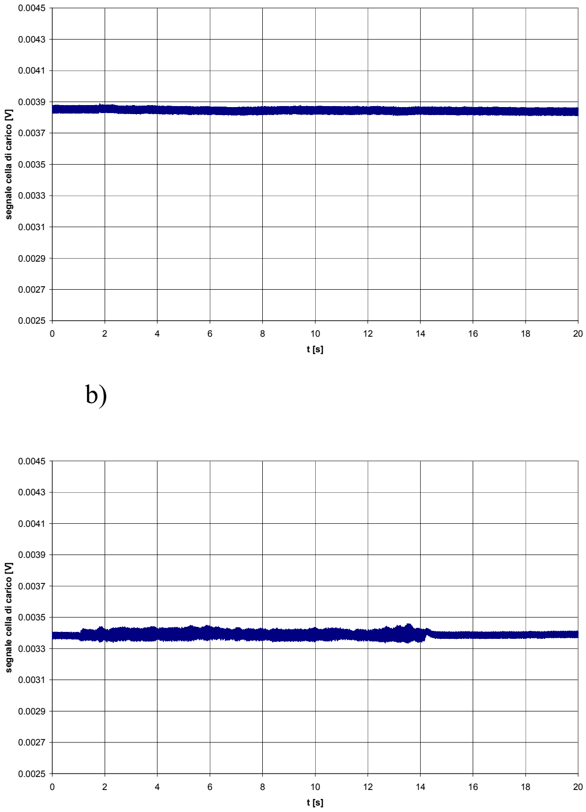

Fig. 12: Force vs. time: continuous note.

Acquisition frequency is 1 kHz. The force is practically constant but the intensity is greater in presence of metallic strings (45,34 N instead of 39,5 N). Modifying the play technique (ghost note, “nota strappata”) the actual signal changes as shown in Fig 13 (respectively up to 55,8 N for metallic and up to 46,5 N for bowels strings).

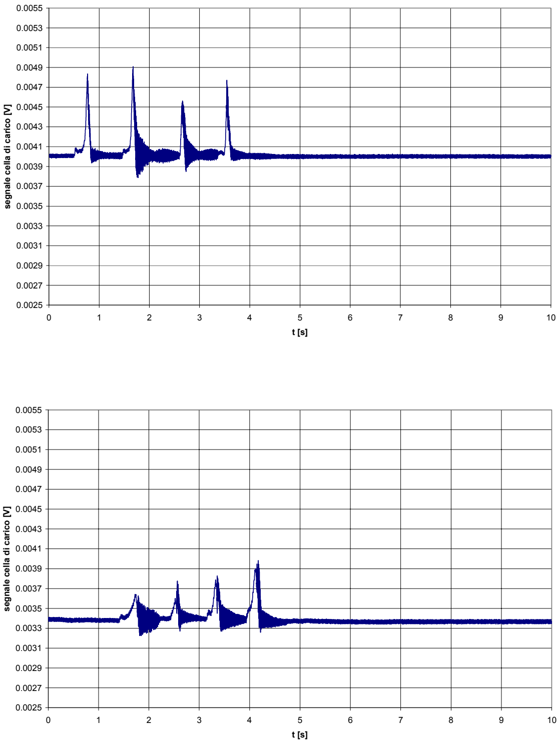

Fig. 13: Force vs. time: ghost note.

A second step of the experimental analysis involves innovative thin film force sensors (Fig. 14), avoiding the use of adjustable bridges.

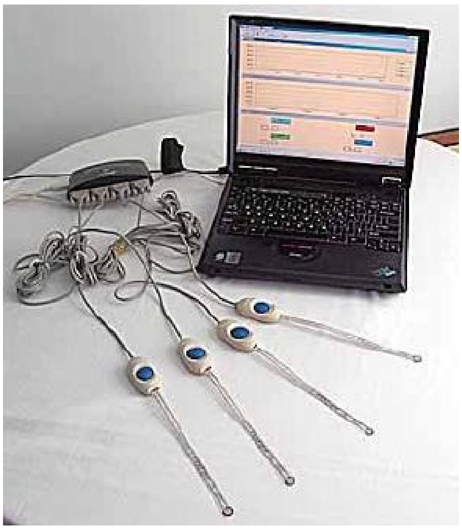

Fig. 14: Thin film force sensors.

Sensors used are thin film tactile force sensors (Flexiforce, produced by Tekscan, inc.). These extremely thin, less than 0,1 mm, and their flexible grid-based device are advantageous, allowing for minimally intrusive measurements, resulting in the least disturbance to the true pression pattern. Each sensor consists on of a matrix of rows and columns of a semi-conductive material that changes its electrical resistance when force is applied to it. The dynamic response is very fast (< 5 µs) and the force ranges (from 0 to 440 N) cover the field interest. This solution applied to violins allows the use of standard bridges, because the relative positions and inclination of the string are not influenced by the presence of the sensors. A couple of sensors are interposed between bridge and soundboard, in order to detect the also the differential force under the inches.

Tensions on strings are measured assembling four micro-load cells in a sensitive array able to be mounted between tailpiece and bridge or near to the peg box. The unit is very compact with easy interface to an acquisition card running on PC.

Deformations on tailpiece and on fingerboard are detected using micro strain gauges (2.5 x 6 mm). Particular care must be applied for the connection (cyano-acrylate glue is used.). The very small dimensions of the transducer don’t modify the mechanical response. This test makes available deformations along the direction of the strain gauges: more general deformation on fingerboard and tailpiece are detected by means micro accelerometers (seismic mass of 0.4 g) as shown, respectively, in Figs. 15 and 16.

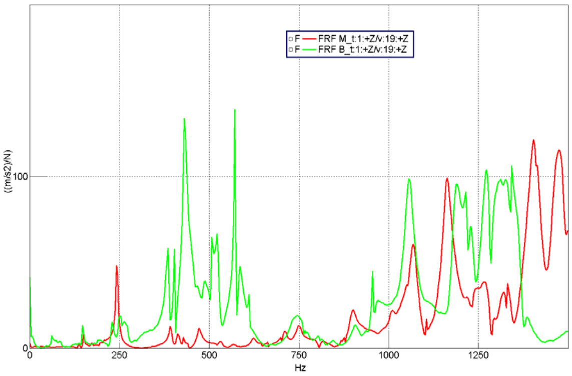

Fig. 15: Dynamic response of fingerboard.

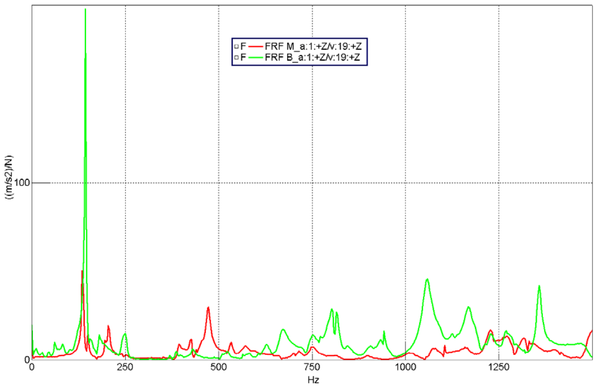

Fig. 16: Dynamic response of tailpiece.

Limits of space don’t allow in this paper a detailed description of all the aspects of this articulated analysis. Some of these require, at present time, further deepening. A fundamental step to compare a baroque and modern violin mounting is represented by the structural dynamic response: mounting modification is essentially structural modification, and this problem is preliminary to the study of the acoustic performances.

6 Friction forces

Friction forces are in particular generated in the contact between string and bridge: here the string, under vibration, tries to change its position. The macroscopic motion is avoided by specific seats designed on the bridge but, micro displacements occur, generating friction. This phenomenon produces an increasing of temperature in these points of contact. A measure of local gradient of temperature provides indirect information about the amount of friction forces.

An example of test is shown hereafter: an infrared portable thermo-camera is used to acquire the local temperature in not invasive way. Fig. 17 shows a detail of a string still played: the maximum temperature occurs, of course, in the contact zone between bow and string. A local area on the bridge where the temperature changes is visible.

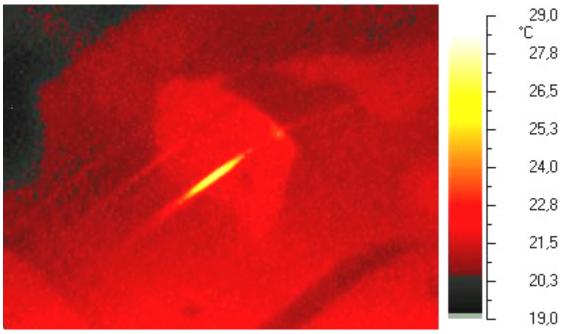

Fig. 17: Thermo-vision of string-bridge area.

More detailed analyses show the local distribution of the temperature in this area (Figs. 18 and 19).

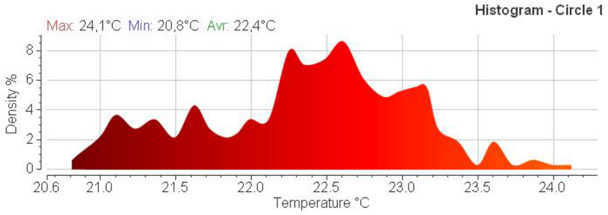

Fig. 18: Density vs. temperature.

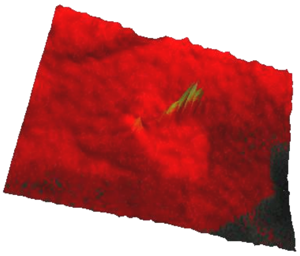

Fig. 19: 3D temperature distribution.

The research activity, still under development, is, at the moment, organized on theoretical studies and experimental tests related to the historical transformation of the violins family, through comparative evaluations based on modal analyses, acoustic responses and tests on persistence of the sound. The same violin, mounted with metallic strings and modern assembling or with bowel strings and modern or baroque assembling, is instrumented and tested from structural and acoustic points of view. The influence of different kinds of bridges and of different tilt angles of the string on modern and baroque assembling is analyzed. Impact tests, experimental modal analyses, sound acquisitions, force and pressure local investigations are implemented using micro-accelerometers, microphones arrays, pressure micro-transducers, load micro-cells and innovative thin film force sensors.

5 Conclusion

An experimental approach oriented to detect in real time forces and deformations in specific points of a violin is proposed. The use of miniaturized sensors and contact less measurement allows a non invasive analysis, applicable also to ancient and rare instruments. The sensing unit is portable, at low-cost, and can be easily managed by a PC; the measure of the actual forces generated during the playing phases makes available information useful to correlate the dynamic mechanical response of an instrument to its acoustic performance.

References

[1] R.Peluzzi, “Tecnica costruttiva degli antichi liutai italiani”, *Leo S. Olschki Ed*., Firenze, Italy, (1978).

[2] C. Gough, “The violin: Chladni patterns, plates, shells and sounds”, *European Physical Journal- Special Topics*, 145, 77-101, (2007).

[3] C. Gough, “ Measurement, modelling and synthesis of violin vibrato sounds”, *Acta Acustica united with Acustica,* 91, 2, 229-240, (2005).

[4] C.Fritz, I. Cross, B. Moore, et al.” Perceptual thresholds for detecting modifications applied to the acoustical properties of a violin”, *Journal of the Acoustical Society of America,* 122, 6, 3640-3650, (2007).

[5] D. Trueman, P. Cook, “BoSSA: The deconstructed violin reconstructed”, *Journal of New Music Research*, 29, 2, 121-130, (2000).

[6] G. Bissinger, “ Modal analysis, radiation and the violins soundpost, *Sound and Vibration*, 29, 8,18-22 (1995)

[7] L.M. Wang, C.B. Burroughs, “Acoustic radiation from bowed violins*”, Journal of the Acoustical Society of America*, 110, 1, 543-555 (2001).

[8] G. Bissinger, “The violin bridge as filter”, Journal of the Acoustical Society of America, 120, 1, 482-491 (2006).