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SUMMARY

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PHYSICAL AND MECHANICAL CHARACTERIZATION OF ANCIENT WOODEN MUSICAL INSTRUMENTS FOR CONSERVATION PURPOSES

Marco Fioravanti[1], Paola Mazzanti[1], Giacomo Goli[1], Gabriele Rossi Rognoni[2], Nicola Sodini[1]*

[1]DISTAF, University of Florence, Italy
[2]DISAS, University of Florence, Italy

Abstract

The conservation of ancient wooden musical instruments is a topic of interest both for wood technologists and conservators. In particular, the state of the wooden sound box is investigated. The climatic conditions of exhibition and performance rooms are monitored. Moreover, the state of tension when tuning is analyzed and both forces and deformations are measured. The results obtained constitute the first step to acquiring the know-how to further the mechanical behavior of instruments subjected to long term loading tests, such as creep and mechanosorption.

1. Introduction

Ancient musical instruments are objects of great value both as historical relics and as real musical instruments that have been played up to now. In order to preserve these precious objects, it is necessary to monitor and analyze the conditions of conservation that are largely dependent on the conservation of the sound box which, in stringed instruments, is typically made of wood.

The aim of this ongoing study is to understand the effects of the events that may occur during the daily life of musical instruments, which, due to their importance, are considered not only as musical instruments but also as components of cultural heritage.

Besides biological decay, wood ageing is determined by the effects of both moisture variation and mechanical stress, as well as the coupling effects determined by their interaction over time. A cyclic variation of environmental parameters (T, RH%) increases the creep of wood, and it has a direct effect on fracture, time dependent deformation and stress relaxation in wood.

In the wealth of studies on the characterization of the acoustic properties of wood, the effects of material elasticity and viscosity on sound speed transmission (or on damping) of wood have been clearly established. Few studies have focused on the measurements of the load applied on the soundboards as effects of the tensioning of the strings.

All of this research is an important source of knowledge, but it does not enable drawing any conclusions for establishing the real effects of using the instruments on their conservation.

The main issues that this study aims to address are the following:

- mechanosorption: does it actually and significantly occur as a consequence of performance (theoretically load is applied and the moisture content of the wood changes during concerts)?;
- load condition: as consequences of load application two opposite phenomena are theoretically possible: wood relaxation and string creep;
- moisture variation: the actual amount and level of moisture variation inside the wood of instruments during their ordinary life (including performances).

In particular this paper is centered on the analysis of:

- climatic conditions of the exhibition and concert rooms;
- tuning forces;
- elastic deformation due to tuning.

* E-mail: marco.fioravanti@unifi.it

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2. Materials and methods

Measurements have been performed on several instruments, but the main source of data comes from a conservation study on Paganini's violin "Cannone" by G. Guarneri del Gesù, which is now property of the city of Genoa in Italy (fig. 1).

2.1. Monitoring temperature and relative humidity of the air

The first step to guarantee optimal conservation of the instrument is to monitor the climatic conditions to which the violin is subjected, both during the exhibition and the performance.

The violin is conserved inside a glass case (fig. 1) in which the temperature and the relative humidity of the air are monitored by two probes (Rotronic, Hygroclip): the first one is set on top of the case and the other one is on the bottom, in order to measure a possible vertical gradient.

A special device was designed to measure the relative humidity of the air and the temperature of the violin during the performance. A miniaturized probe (Sensirion SHT75) is set in the hole that fits the end button, too. An electronic board (tmote sky, Moteiv), set between the top and the chin rest, sends the collected data to a laptop by radio wave system.

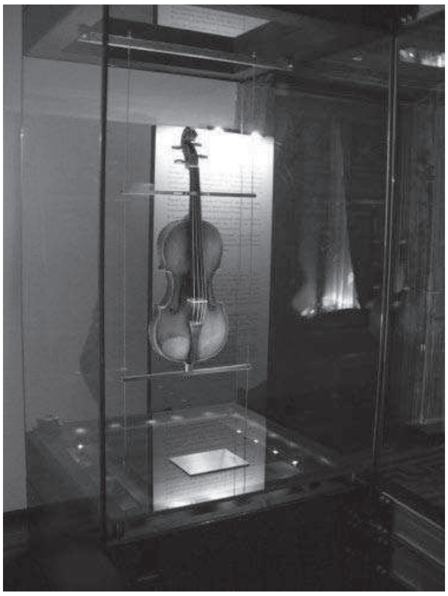


Fig. 1: the violin, mounted on the frame in the exhibition case.

2.2. Monitoring the weight variation

Climatic variations, particularly RH variation, inside the case are responsible for the violin weight variation. In order to monitor it, the instrument is hung on a frame which is placed on the scale *(ohaus, AV2102C*) that is connected to a PC in order to continuously collect the weight data. The data are saved in a txt file according to an acquisition rate of one reading every five minutes.

2.3. Measuring tuning forces

During the tuning, the strings produce a force that depends on the frequency, the length and the unit mass of the string itself. In order to measure force, a specific load cell was designed at DISTAF in cooperation with Deltatech. It is an exact copy of the bridge mounted on the "Cannone". It is made of iron and is equipped with extensometers (fig. 2). This measuring bridge is able to measure the force produced by the strings according to two perpendicular axes, named Z and X. Along the X axis we measure the transversal force, that is the force that develops along the perpendicular directions to the main axes of the violin itself, and along the Z axes we measure the force orthogonal to the top. The accuracy is 1mV that is the equivalent of 0,018N. The data are collected by an electronic board, NI USB621, and sent to the PC to guarantee continuous acquisition.

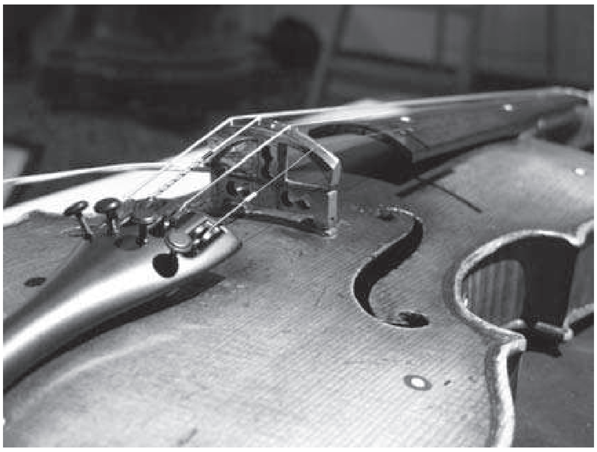


Fig. 2: the equipped bridge mounted on the violin.

2.4. Measuring elastic deformation

The force produced during tuning induces a deformation of the violin. The immediate deformation, that is the elastic deformation, is measured by an optical 3D digitizing system. The measure is based on the interferometric principle, that is the 3D scanning of the instrument due to the intersection of two different light beams. It enables generating a perfect reproduction of the object and the measure of its deformation according to an accuracy of 20 µm. The scanning is made by ATOS III scanner and Geomagic Studio carries out the image elaboration, in cooperation with DigiLab (fig. 3).

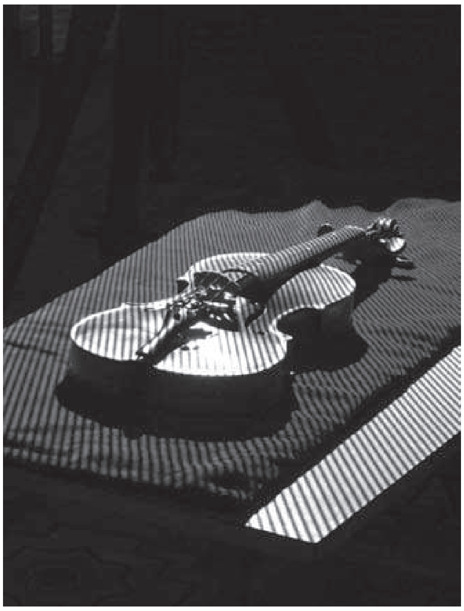


Fig. 3: the 3D scanning of the violin.

3. Results and discussion

3.1. Monitoring climatic conditions and weight variations

Inside the conservation case the climatic conditions can be considered stable during the whole of 2007. The temperature varied from 21°C to 25°C during the whole year. The RH% usually moved about 57.5% for the whole year, except for the autumn when the RH decreased to 51%. As a consequence, the weight variations are small, approximately 0,5 g that is 0,1% of the violin weight. An interesting thing happened after concerts. Usually the performance room is drier than the exhibition case, that is why the violin loses weight, but, after being in the case again, it continued to lose weight notwithstanding the increased relative humidity of the air. It has been assumed that the influence of the climate inside the case was great. That is why it is necessary to measure the climatic conditions inside the sound chamber (the empty space between the two boards) during performances (fig.4).

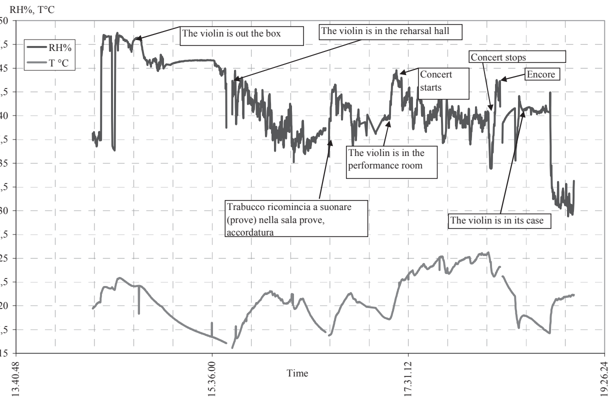


Fig. 4: climatic conditions inside the violin's sound chamber during a performance.

The analysis of weight variation during a performance is shown in Fig. 5; the violin loses about 1 g during the concert itself because of the different climatic conditions (fig 4). After this extraordinary event, the required time to regain the original weight, which is considered the equilibrium weight, is about one month notwithstanding that the climatic conditions in the conservation case are constant (fig 5).

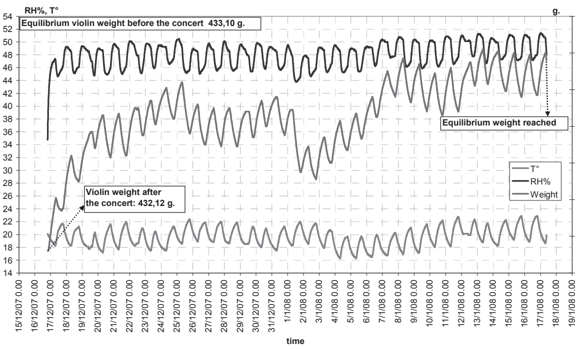


Fig. 5: time to regain the equilibrium weight after the concert.

3.2. Measuring tuning forces

The equipped bridge gives useful data on the forces produced during tuning (fig 6).

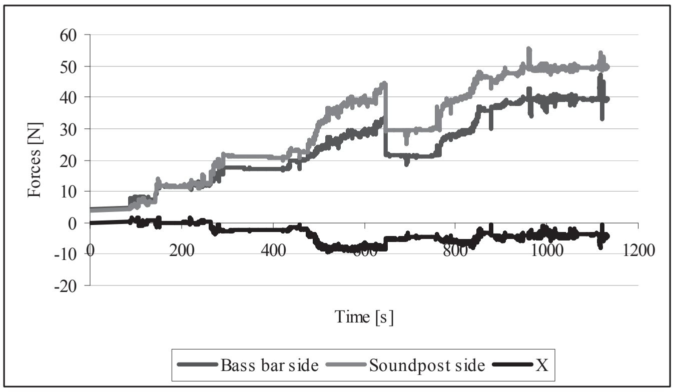


Fig. 6: forces shown during the tuning.

Looking at the Z axes we can see that on the soundpost side the forces, amounting to 50 N, are higher than the bass bar side (40 N). This is due to the different longitudinal tension necessary to tune the strings: the MI string is on the soundpost side and it is the one that needs greater force to be tuned. The gap between the two sides is 10 N, that is equivalent to 20% of the maximum force.

Analyzing the forces parallel to the top of the violin (X axes), we observe low values, around 4 N, when the violin is tuned. It means that the tuning stress according to that direction is negligible compared to the orthogonal forces (4,5% of the orthogonal forces).

3.3. Measuring elastic deformation

The results of the 3D scanning of the tuned violin (fig. 6 for the forces shown during measurement) show the deformation of the sound box, c cupid arch, and the high movement of the neck. Tuning produces a tension of the strings that is balanced by a deformation of the violin, that in simple terms consists of a compression of the top and a tension of the back. The neck is pulled up 1,335 mm by the action of the strings (the red zones in fig. 7a), and at the same time the fingerboard is pushed down 0,55 mm, which produces a rotation of the neck around its insertion point in the sound box.

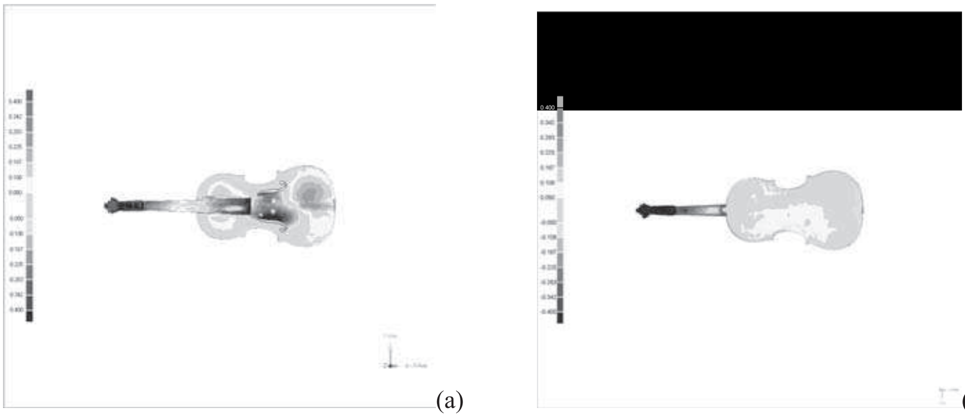
The sound box is not deformed on the edges (the green zones in fig. 7a), but it shows a clear cupid arch deformation at the centre. In the bridge area the top is pushed down by the direct orthogonal forces expressed by the bridge itself (blue zone in fig. 7a). Near the end button and the fingerboard the top is obviously pulled up by the action of the tailpiece on one side, and the neck on the other, while the bridge acts as if it was a separating line.

The deformations are asymmetrical on the top, because of the presence of the soundpost and the bass bar on the opposite sides. Where the soundpost is present the deformation produced by the bridge stress is rather small (0,117 mm), because the soundpost itself produces a restraining force. As a consequence of this mechanism, the deformation of this side of the top, shown as convexities, is more evident far from the bridge (0,222 mm near the fingerboard and 0,257 mm near the tailpiece).

On the opposite side, the bass bar, set along the top, does not contrast the bridge stress (the deformation amounts to 0,457mm), but it makes the violin stiffer far from the bridge (0,181 mm near the fingerboard and 0,029 mm near the tailpiece).

Therefore the deformations are greater in the bridge area and smaller far from it.

On the back (fig. 7b), the neck and the end button area are pushed up by the strings (blue and light blue zones, fig. 7b) . The sound box shows no deformation, or very small deformations (green zones, fig. 7b) limited between +0,05 and -0,05 mm, except for the soundpost area (yellow and orange areas, fig. 7b) and the deformation amounts to 0,13 mm. In fact, the soundpost produces a localized transversal compression on the back. Whereas on the other side the presence of the bass bar, which is not attached to the back, does not transmit deformations to it.



(a) (b)

Fig. 7: elastic deformation on the top (a) and the back (b) of the violin tuned up with a string set mounted on during the performances.

4. Conclusions

The work described herein is part of a more complex study on improving the conservation conditions of wooden musical instruments, particularly violins. Results obtained thus far relate both to the climatic conditions and mechanical stresses to which the violins are subjected during exhibition and performances.

4.1. Variation in climatic conditions related to weight variations

The climatic conditions inside the exhibition case are stable and the weight variation of the violin is limited.

The main variations, both in relation to environmental conditions and weight, relate to the performance.

Moving the instrument to a usually drier room for concerts, results in loss of weight (1g), which needs about a month to be regained. This weight variation suggests that the violin is not perfectly insulated because of the imperfect waterproofing of the varnish and the contribution of the inside of the sound box, which is raw.

4.2. Mechanical behaviour

The study of the elastic deformation shows the deformative behaviour of the violin which can be generalized as follows. The violin can be divided in two parts: the neck and the sound box. The neck is subjected to a rotation around its insertion point on the sound box. The sound box is subjected to compression of the top and to tension of the back, in simple terms. The marginal areas are not deformed, while the central part shows a cupid arch deformation.

This knowledge of the elastic deformation of the violin represents the first step towards furthering the mechanical behaviour of the instrument subjected to long term loading such as creep and mechanosorption.

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