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Measurement and modelling of mass and dimensional variations of historic violins subjected to thermo-hygrometric variations: The case study of the *Guarneri "del Gesù"* violin (1743) known as the "*Cannone*"

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ABSTRACT

This paper presents a study regarding the hygro-thermal conditions to which the violin *Guarneri "del Gesù"* (1743), known as the "*Cannone*", is subjected during its conservation and occasional use in concerts with special attention on its mass and dimensional variations. Several environmental measurement campaigns were planned and carried out using relative humidity and temperature probes. The violin mass variation was measured continuously inside the display case where it is conserved, and before and after concerts by means of a special exhibition frame integrating a precision balance. These measurements enabled reproducing the thermal and hygrometric variations to which the violin is normally subjected using a purposely-developed portable climatic chamber, and also enabled measuring the consequent hygroscopic and thermal deformations in selected points by means of a purposely-developed measuring frame. An empirical model for computing the mass variations according to the variation of environmental conditions was implemented and verified and the typical mass variation consequent to the use of the violin during concerts was also determined. The violin's thermal and hygroscopic deformations were measured in selected points for given temperature and relative humidity steps. The paper includes a discussion about the possible impact of hygro-thermal variations on violin conservation.

1. Research aims

The results presented in this research paper are part of a larger project that aims to investigate the properties of historic violins in order to provide suggestions for regulating their use and improving their conservation. The hygro-thermal variations undergone by the violins, during their conservation and during their rare use in concerts, are analysed as well as the reactions of the violins. The potential impact of these hygro-thermal variations is finally analysed.

2. Introduction

Historical musical instruments maintain unaltered over the time the quality of their sound that seems to improve with the instrument age. Despite their age, musicians and violinmakers consider most of these instruments as musical instruments rather than cultural heritage oeuvres and, in some cases, their original structure has been completely re-adapted according to the musical needs.

This is not the case of the "*Cannone*" violin, made in 1743 by Giuseppe Bartolomeo *Guarneri "del Gesù"* and owned by the great violin player Niccolò Paganini [1]. After Paganini's death, the violin, in accordance with his will, was left to the city of Genoa, where he was born. This was an important fact for the conservation of the violin because after Paganini's death, the instrument has maintained its integrity, representing one of the cases where the cultural function of the object has become predominant to the musical one.

Nowadays, the "*Cannone*" is on display in the Paganiniana Collection in Palazzo Tursi, which is part of the Strada Nuova Museums located in Genoa (IT). In order to preserve this precious object, a complete study was carried out, the first part of which is presented in reference [2]. Aim of the study has been to monitor the physical and mechanical behaviour of the violin during its ordinary conditions, both in the conservation case and during occasional concerts, in order to assess possible inference of those parameters on the instrument conservation.

As it is well known in wooden artefacts, the effects of both moisture variation and mechanical stress, as well as the combined effects of their interaction over time, are at the origin of the so-called mechano-sorptive behaviour of the material, that

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might determine a potential modification in the ultrastructure of the wood (physical ageing [3]). These processes, although not completely understood until now, are well known and described in scientific literature where an excellent review can be found in [4]. Within historic objects, much research has been carried out on the effect of moisture variations on panel paintings [5–8] but very limited research has been carried out on the effects of these variations on musical instruments. In this work, the elastic deformation in selected points was assessed, and the hygroscopic behaviour of the violin during conservation was studied and modelled according to variations in environmental conditions. A measuring frame was implemented and tested as well as a portable climatic chamber in order to directly determine the deformations of the violin corresponding to given temperature (*T*) and relative humidity (*RH*) variations. The thermal and hygroscopic deformations perpendicular to the soundboard were determined, and the resulting values were discussed according to the typical variations to which the violin is subjected during conservation and during concerts.

3. Materials and methods

3.1. Measurement of environmental conditions and violin mass variations inside the conservation/display case

In order to evaluate the typical moisture content changes in the violin during its conservation, a mass monitoring system inside the display case was implemented and measurements were performed for a time period of about three years. A precision balance (0.01 g resolution ± 0.02 g of linearity) was used (Fig. 1a) and data was collected using a PC and a RS232 connection. The balance was covered with a box painted like the display case so as not to alter the visitor experience (Fig. 1b). Two probes were used in order to collect *RH* and *T* (accuracy ± 1% *RH* and ± 0.3 °C) by a computer USB acquisition board. The acquisition was driven with National Instruments LabVIEW and data collected and saved every five minutes.

In order to calculate the average yearly *T* and *RH*, to be compared with the climatic data of Genoa town for the last three decades as from reference [9], the daily *max* and *min T* and *RH* inside the display case were computed, averaged on one month base and finally the months averaged for one year.

3.2. Implementation of a portable climatic chamber for in-situ experimentation

Experimentation was then conducted directly in the display case inside a Plexiglas box (0.1 m^3 of air volume), which was thermally insulated by polystyrene sheets (Fig. 2a) and controlled for *RH* and *T*. The system within 22 hours of uninterrupted work for an *RH* target of 47% performed with a SD of 0.5% *RH* and for a *T* target of 26 °C performed with a SD of 0.04 °C giving excellent results.

3.3. Measurement of violin deformation

In order to measure the violin deformations, a special frame made of aluminium shaped beams equipped with LVDT transducers was developed (Fig. 2a). Measurements were carried out only in a vertical direction and two measurement lines with a total number of seven transducers (three in the front line and four in the rear line) were implemented. The lateral transducers (placed on the ribs) had the double function of measuring the deformation of the rib zones and providing a reference in order to recalculate the deformation of the central transducers. Selected points for measurement as well as the reference names and some main dimensions are shown in Fig. 2b.

The tuning was carried out using strings D'Addario Helicore type "Medium". The forces acting on the strings were as from manufacturer's specifications: 84.37 N for E, 57.61 N for A, 52.16 N for D and 46.27 N for G. These forces correspond to a total longitudinal force acting on the violin of 238.07 N and to a normal force acting on the bridge of 88.82 N (whom 49.56 N on the *sound-post* side and 39.26 N on the *bass-bar* side) as described in reference [2].

In order to allow a free movement of the violin while being tuned, a four-point holding system placed at the front and rear extremities of the body was adopted. The violin was held by assembly clamps glued on the frame and lightly tightened in order to avoid undesired stresses. For the measurements, LVDT transducers were used with 1 mm stroke and integrated electronics (linearity < 0.125% of the stroke and negligible temperature effect being 0.015% of the stroke $°C^{-1}$).

Since the outputs from the transducers (named as shown in Fig. 2b) represent the movement of the individual measured points in the vertical plane, a further processing was implemented in order to:

- express the rib deformation as an average of left and right measurements,
- remove the contribution of rib deformation from the central points deformation.

For this reason, $front\overline{LR}$ is the average displacement of the ribs in the front line; $rear\overline{LR}$ in the rear line; $front\overline{C}$, $rear\overline{CL}$, $rear\overline{CR}$ the movements of the central part of the soundboard relative to the ribs. The data were processed according to equations (1) to (5). *dL*, *dR* and *L* are as defined in Fig. 2b. The rear transducers line processing method is explained in Fig. 2b.

$$front\overline{LR} = (frontL + frontR)\,2 \tag{1}$$

$$front\overline{C} = frontC - front\overline{LR} \tag{2}$$

$$rear\overline{LR} = (rearL + rearR)\,2 \tag{3}$$

$$rear\overline{CL} = rearCL - rearL - \left(\frac{rearR - rearL}{L}\right) \bullet dl \tag{4}$$

$$rear\overline{CR} = rearCR - rearL - \left(\frac{rearR - rearL}{L}\right) \bullet (L - dR) \tag{5}$$

The transducer output was acquired by a 16-bit USB board (accuracy 0.0014 V corresponding to 0.3 μm in the described set-up). The acquisition rate was set to 10ks/s per channel and the data to be plotted or written to file come from averaging the data collected during the latest second for each channel. The averaging of the over-sampling enabled a high degree of precision. In order to avoid disturbances due to accidental vibrations, a glass platform was used, resting on four gel vibration dampers.

With this set-up, the following measurements were performed:

- the elastic deformation of the violin when tuned (the measurement is performed immediately before and immediately after tuning up the violin);
- the thermal deformation of the violin when subjected to temperature changes (temperature steps of about one hour were performed going from 26 °C to 26.6 °C, from 26.6 °C to 27.2 °C, from 27.2 °C back to 26.6 °C and finally a step of two hours going from 26.6 °C back to 26 °C);
- the hygroscopic deformation of the violin when subjected to a RH variation of –9% for a two hours time period.

3.4. Measuring the frame's thermal expansion

Before starting the measurements on the violin, the thermal behaviour of the measuring frame was determined in order to be able to correct the measured thermal deformation of the violin. The test was performed by fixing the clamps on the frame with the glue