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Neutron imaging as tool for investigations on historical musical instruments

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ABSTRACT

In this paper, we describe, why and how neutron imaging methods are applied to contribute to the knowledge about historical music instruments, either brass based or using wood as structural material. Beside the recovery of constructive details of old brass wind instruments with the aim to build equivalent replica, the influence of moisture on inner corrosion has been investigated. On the other side, wood properties are strongly influenced by the moisture uptake from the varying environment and the coverage and protection by varnish and lacquer were studied systematically using neutron transmission measurements.

1. Introduction: why to inspect musical instruments

Musical instruments have been used since the very early time of human mankind. During development and improvements of such devices state-of-the-art materials were involved and modern production techniques have been applied. Both material selection and instrument assembly contribute to the perfection of achievable sound. It is still surprising that e.g. century old violins have such a unique quality allowing them to compete with contemporary modern instruments.

Over the centuries many types and classes of musical instruments have been developed. Many types of musical instruments are still used nowadays but often adapted to up-to-date production techniques and using modern materials. However, little changes in material and production can already modify the sound and the kind of playing. Hence, a historical piece of music may sound different on modern instruments than on instruments used at the time, when the piece was written. This underlines the necessity to conserve historical musical instruments not only as object but also to furthermore preserve their sound.

To preserve musical instruments and their sound as cultural heritage necessitates their study. Investigations using non-destructive techniques examine different aspects:

- Status; it is important to derive information on the status of historic musical instruments in order to determine whether and how it has to be treated by the conservators to be preserved.
- Construction/functional design; closer examination of the instrument allows to understand how it was manufactured and how sound is generated. This enables the reproduction of precise replicas of the instruments thus preserving their sound.
- Monitoring the impact of external factors on the instrument e.g. moisture introduced by playing a wind instrument; understanding the problems of temporal or permanent material changes (like corrosion or other kind of degradation).

The materials mostly used for music instruments structure are wood and metals (brass and other alloys). The projects presented in this paper are related to brass wind instruments and violins. In both cases the influence of moisture is of importance. This is a major reason to prefer neutron imaging better than studies with X-rays: hydrogen delivers a high contrast for neutrons while the metal is more transparent.

The particular questions in the three projects are:

- How to build replicas of old instruments? How close we can come to the original with modern production means and materials available?
- Is it allowed and possible to play on historical instruments? What is the impact of moisture induced by playing on the integrity of the instruments (in particular with respect to corrosion)?
- What is the influence of moisture on the varnished wood of a violin? How to prevent or to tune the moisture impact on wooden instruments like in a violin under realistic environmental conditions? Here, the surface treatment with different varnish and lacquer systems is of high importance.

Due to the complementarity to X-rays, neutron imaging techniques appear to be very well suited for such investigations. Radiography and tomography with neutrons were applied at the imaging facilities of the

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Fig. 1. Outer view of the tomography study of a 19th century cornet with thermal neutrons at the NEUTRA facility at PSI; the voxel size is on the order of 0.1 mm.

Paul Scherrer Institut (PSI), Villigen (CH) with suitable setups fitting to the dimensions of the samples and real music instruments and by using of dedicated infra-structure.

The achievable image quality in neutron tomography is demonstrated by the example in Fig. 1 of a 19th century cornet.

2. Used facilities and infrastructure

2.1. The NEUTRA facility (https://www.psi.ch/sinq/neutra/, n.d.)

Neutron imaging is established at the thermal neutron beam of the NEUTRA facility at the Swiss spallation neutron source SINQ at PSI. The beam diameter at the end position is about 40 cm and enables therefore the study of extended objects such as full size musical instruments. A second measuring position with ca. 20 cm beam diameter but higher beam intensity is established in half-way distance. It is suited to study samples with higher spatial resolution and in time resolved modes.

The most common detector for neutron imaging under these conditions is based on a highly sensitive camera system looking via a mirror onto a scintillator screen which converts the absorbed neutrons into visible light. Depending from the neutron flux at the different measuring positions as well as on the scintillation material and the scintillator thickness, exposure times can vary from few seconds to several minutes.

Although the neutrons are most suitable for investigations within the three projects under discussion, an additional X-ray source in front of the beam exit can be used for similar and comparative X-ray image data acquisition. This data fusion approach is very useful (Mannes et al., 2015) in some cases and has been taken in this study for the justification of the better neutron solution, see below.

2.2. Climate chamber

For some systematic studies it is very important to perform the investigations under well-controlled conditions with respect to moisture, air flow and temperature. This is valid in particular for the studies involving hygroscopic materials such as wood.

A Climate chamber has been designed and build with the following boundary conditions:

- Neutron transparent inlet and outlet windows for the beam to enable a nearly unperturbed acquisition under operative conditions
- Moisture content of the air controlled between 5% and 90% relative humidity
- Temperature range from −20 °C to 100 °C

This very flexible device can be used either under static or dynamic conditions with well-defined operational parameters.

The device is optimized for the medium sized detector system with a field of view (FoV) of up to 15 cm by 15 cm available at the PSI imaging facilities. A detailed description of the climate chamber can be found in (Mannes et al., n.d.).

2.3. Moisture generator

We used a moisture generator type “aGEPRO-V4” (by ADROP, Fürth, Germany). This device works along the principle of mixing dry and humid air. The dry air is provided by the pressurized air supply system at SINQ, while the humid air is obtained from an internal humidifier chamber. The two gas flows are adjusted with a mass flow controller, the actual moisture regulation is affected by a reference moisture sensor and a microcontroller. This system is used for the climate chamber system but also in the “stand alone mode” providing an air flow with defined temperature and moisture simulating the exhaled air while the playing of a brass wind instrument.

3. Projects

The three projects are not directly linked, but each take profit from the outcome and experiences of the previous ones: in a first project, we demonstrated how neutron imaging can be used to obtain information on the structure and design of brass wind instruments (using radiography with imaging plates, tomography with the camera setup). A second project focused on the playability of historical musical instruments, where the impact of diurnally repeated playing over a period of a year was monitored on historical instruments with particular respect to corrosion. In a third project, the influence of different varnish systems on the hygroscopic behavior of violin wood was investigated, in order to obtain a deeper understanding of the fundamental phenomena. For all three projects, neutron imaging has been seen to be the most useful technique with respect to the needed sensitivity, spatial and temporal resolution – and their combination.

The projects are described in detail in (Mannes et al., 2016a; Mannes et al., 2016b; v. Steiger et al., 2014; v. Steiger et al., in press).

3.1. Analysis of 19th century brass instruments

This interdisciplinary project supported by CTI (Swiss Commission for Technology and Innovation) had the aim to produce exact replicas of historical brass wind instruments from the 19th and early 20 century. Beside the material determination (composition, alloy structure, mechanical properties – done by EMPA) the aim of the non-invasive investigations with neutrons (and comparative with X-rays) was the precise analysis of the geometry of the instruments. These data are needed to make the replica with the identical wall thickness as the original in all parts and to have all fittings and soldering connects done correctly. In this way, a real construction plan could be derived.

Figs. 2 and 3 compare neutron and X-ray data of the same object. It becomes obvious that only the neutron transmission data are good enough to verify the inner wall edges correctly. The X-ray data are higher in contrast and the inner wall position vanishes by the scattering and attenuation effects in the material.

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The tomography data (see an example in Fig. 4) enable slices and views at any position of the investigated instrument where the walls, the connections and the very details like valves composition are precisely represented. These overview data, in particular the material thicknesses, were used to build the replica in the workshop of “Egger Blechblasinstrumentenbau” in Basel, Switzerland. In a concert of the “Swiss military orchestra” at PSI in early 2014 with usage of the instruments a comparison between the real old and the newly built ones became possible.