David Mannes / Eberhard Lehmann

Monitoring the Condition of Played Historical Brass Instruments by Means of Neutron Imaging

Abstract Neutron imaging is a non-destructive testing method that functions according to principles similar to x-ray imaging. In contrast to x-rays, neutrons can generally penetrate metals rather well, but at the same time they have a high sensitivity for hydrogen. This makes neutron imaging – which includes radiography (investigations in 2D) as well as tomography (3D) – an ideal method for studying the impact of playing historical brass instruments. Playing a brass instrument creates an accumulation of moisture inside the instrument, which can eventually lead to the generation and expansion of corroded areas inside it. This moisture, along with many other products of corrosion, contains hydrogen, which provides a high degree of contrast for neutron imaging.

This article explains how neutron imaging was used to monitor the condition of historical brass instruments, i.e. the changes in the internal corroded areas, by comparing 3D CT-data sets acquired before and after the instruments had been played on a regular basis over the period of fourteen months.

Introduction Musical instruments reflect the state of knowledge of the period of their conception and manufacture. They are thus subject to constant development and changes in habits. Not only do the manufacturing techniques of a certain instrument type change from one era to the next, but so does the way these instruments are played, and how they sound. Music composed in a certain era for instruments of that period thus sounds different on these instruments than on contemporary instruments. In recent years, historically informed performances have received more and more attention in which an orchestra plays on historical instruments or replicas in order to reproduce the original sound. This has resulted in an increasing demand for more information on historical instruments. Deeper insights on their geometry, structural design and the materials utilised in them have allowed us to manufacture more and more accurate replicas.[1] The pros and cons of playing historical instruments are much debated, because

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[1] David Mannes/Eberhard Lehmann/Adrian von Steiger: Untersuchung von historischen Blechblasinstrumenten mittels Neutronen-Imaging, in: *Romantic Brass. Französische Hornpraxis und historisch informierter Blechblasinstrumentenbau. Symposium 2*, ed. by Daniel Allenbach, Adrian von Steiger and Martin Skamletz, Schliengen 2016 (Musikforschung der Hochschule der Künste Bern, Vol. 6), pp. 439–445; Adrian von Steiger/Marianne Senn/Martin Tuchschmid/Hans J. Leber/Eberhard Lehmann/David Mannes: Can we Look over the Shoulders of Historical Brasswind Instrument Makers? Aspects of the

DOI: 10.26045/kp64-6179-007

playing an original stands in opposition to the notion that such historical artefacts should be preserved and kept safe.[2] This article shows how neutron imaging can be used to investigate certain aspects of the impact that playing can have on the state of historical brass instruments, with special attention to the development of corrosion. Neutron imaging is a non-destructive testing method that is well suited to investigating historical musical instruments or other objects of our cultural heritage.[3]

Working principle In neutron imaging, neutron radiation is used to probe an object and to generate images. Classical neutron imaging, like x-ray imaging, is based on transmission measurements. An object is placed in front of a detector, and exposed to radiation that is partially attenuated by the object; the beam that is transmitted is then registered by the detector. The attenuation of radiation occurs in a first-order approach according to the Beer-Lambert law:

$$I = I_0 \cdot e^{-\Sigma \cdot z} \qquad (1)$$

where I is the intensity of the transmitted radiation, I_0 is the intensity of the incident radiation, Σ is the attenuation coefficient and z the thickness of the object. The attenuation coefficient is a material parameter which describes to what extent a certain material (that is, the element composition with a specific density) attenuates the radiation. The resultant transmission images provide 2D information on the material, structure and density of the object, integrating the attenuation information along the beam trajectory projected onto the detector.

Materiality of Nineteenth-Century Brass Instruments in France, in: *Historic Brass Society Journal* 25 (2013), pp. 21–38, https://doi.org/10.2153/0120130011002.

[2] Adrian von Steiger/Daniel Allenbach/Martin Ledergerber/Bernhard Elsener/David Mannes/Federica Cocco/Marzia Fantauzzi/Antonella Rossi/Martin Skamletz/Martin Mürner/Marie Wörle/Emilie Cornet/Eberhard Lehmann: New Insights into the Conservation of Brass Instruments. Brass Instruments Between Preventive Conservation and Use in Historically Informed Performance, in: *Historic Brass Society Journal* 30 (2018), pp. 85–101, https://doi.org/10.2153/0120180011005.

[3] Giulia Festa/Giovanni Tardino/Laura Pontecorvo/David Mannes/Roberto Senesi/Giuseppe Gorini/Carla Andreani: Neutrons and Music. Imaging Investigation of Ancient Wind Musical Instruments, in: *Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms* 336 (2014), pp. 63–69, https://doi.org/10.1016/j.nimb.2014.06.020; Sebastian Kirsch/David Mannes: X-Ray CT and Neutron Imaging for Musical Instruments. A Comparative Study, in: *Wooden Musical Instruments. Different Forms of Knowledge. Book of End of WoodMusICK COST Action FP1302*, ed. by Marco A. Pérez and Emanuele Marconi, Paris 2018, pp. 157–169; David Mannes/Eberhard Lehmann/Alex Masalles/Katharina Schmidt-Ott/Alexandra von Przychowski/Florian Schmid/Steven Peetermans/Katja Hunger: The Study of Cultural Heritage Relevant Objects by Means of Neutron Imaging Techniques, in: *Insight. Non-Destructive Testing and Condition Monitoring* 56/3 (2014), pp. 137–141, https://doi.org/10.1784/insi.2014.56.3.137.

3D information can be generated by performing a computed tomography. For this, the object is rotated between the acquisition steps, resulting in a multitude of projections from different viewing angles. These projections can then be processed by special algorithms to reconstruct tomograms, that is, slices of the investigated object perpendicular to the rotation axes. The stack of reconstructed tomograms represents the three-dimensional information, the volume data set, which can be further processed, evaluated and visualised. Figure 1 shows a schematic of the workflow of such investigations.

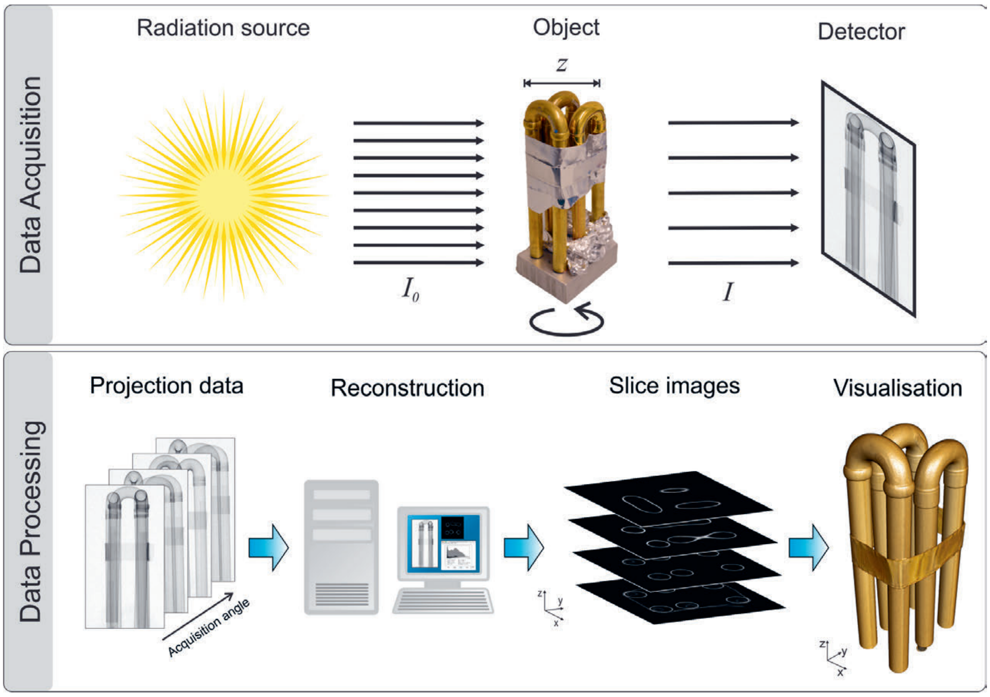

FIGURE 1 Schematic presentation of the workflow of an investigation using computed tomography, from data acquisition to visualisation

The experiment For the investigations presented here,[4] neutron tomography data were obtained on the thermal neutron imaging beamline NEUTRA at the Paul Scherrer Institute in Villigen.[5] The goal of the project was to investigate how playing historical brass instruments regularly impacts on their physical state, with a special focus on corrosion.

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[4] Carried out within the framework of the project described in this volume and in von Steiger/Allenbach/Ledergerber/Elsener/Mannes/Cocco/Fantauzzi/Rossi/Skamletz/Mürner/Wörle/Cornet/Lehmann: New Insights into the Conservation of Brass Instruments.

[5] See Eberhard Lehmann/Peter Vontobel/Luzius Wiezel: Properties of the Radiography Facility NEUTRA at SINQ and Its Potential for Use as European Reference Facility, in: *Nondestructive Testing and Evaluation* 16 (2001), pp. 191–202.

15 tuning slides from the project instruments were inspected at the beginning and end of the project, in order to be able to observe changes that occurred due to playing the instruments on a daily basis over the period of fourteen months. As detector, scintillator-CCD-camera systems were used with an Andor iKon-L and a 100 µm thick ^{6}LiF:ZnS scintillator, with a field of view of 241 mm × 241 mm and a pixel size of 154 µm for large tuning slides, and field of view of 150 mm × 150 mm and a pixel size of 98 µm for smaller tuning slides. For the tomography, 625 projections were acquired over 360° that were subsequently reconstructed using the Octopus Imaging Software package.

Data evaluation The analysis and evaluation of the volume data were carried out using the software package VG Studio Max. Here, different approaches were used to compare the state of the tuning slides at the beginning and end of the project:

- a variance comparison of the inner surfaces;
- unrolling the tuning slide cylinders to create a virtual plane layer;
- comparison of sections at identical positions.

The variance comparison only takes into account the surface of the object determined by the software algorithm. After the surface determination, the tuning slides are registered, that is, the volume data are aligned in such a way that both data sets are superimposed on each other. Subsequently, the position of every surface point of the tuning slide in its end state is compared to the position of the presumed identical point of the tuning slide in its initial, reference state. The differences are subsequently shown using a colour code for the extent to which the position of the individual surface area varies from the reference state (Figure 2).

In another approach, cylinders were fitted in each leg of the tuning slides and virtually unrolled, allowing us to compare the grey levels (which correspond to a mapping of the attenuation) for every point between the start and the end. In a third step, regions identified by unrolling are examined more closely by specifically positioning section planes in potentially corroded regions.

Results and discussion Variance comparison The variance analysis was carried out under the premise that an increase of corrosion inside the tuning slides would occur along with a displacement of the inner surfaces due to the growth of the corroded areas. In very few regions of the tuning slides inspected, small positive deviations could be found (see the circles in Figure 3). Such increases were very small, only in a range of up to circa 0.25 mm.

In individual spots, a loss in material can be found (see the black arrow in Figure 3). Here, a small piece of solder seems to have fallen off, perhaps due to cleaning the instrument.

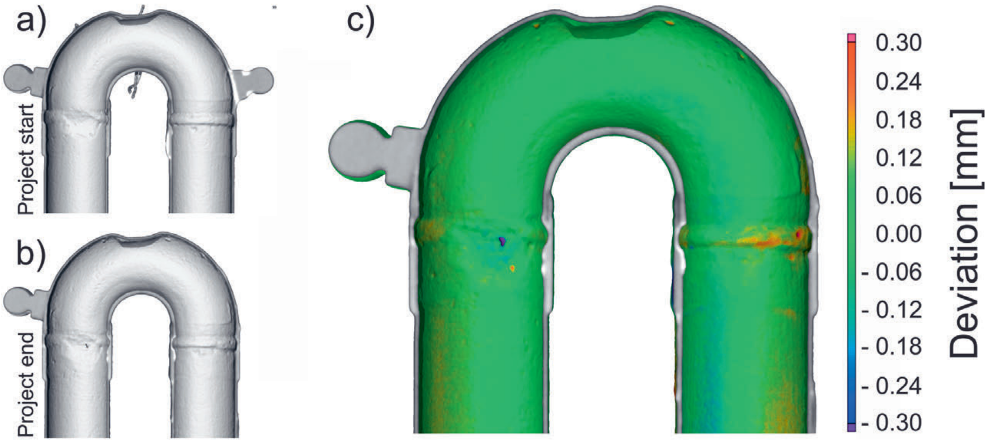

FIGURE 2 Variance comparison of the volume data set of a tuning slide (HKB 5024.2); a) shows a half-section view of the 3D visualisation at the beginning of the project, b) at the project's end; c) shows the differences between the status at the end and the reference state, coded in false colours.

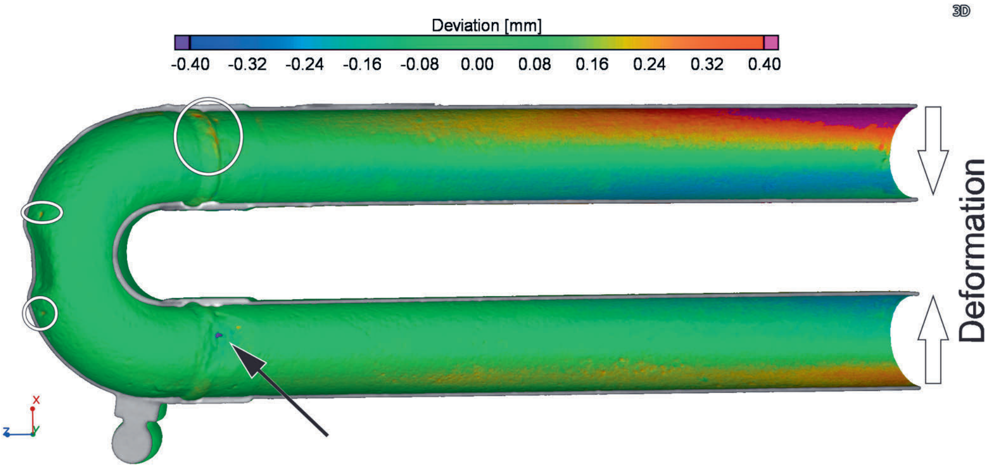

FIGURE 3 3D half-section view of a tuning slide (HKB 5024.2); the colour code shows the deviation of the surface at the end of the project compared to that at the start. The circles show very small regions with a small increase in material, while the black arrow shows a loss of material (perhaps due to cleaning). The colouring at the end of the tuning slide legs shows strong deformation.

One problem that occurred in a large percentage of the tuning slides inspected was deformation of the slide legs. As can be seen in Figure 3, the legs show a relatively pronounced deformation, especially towards their end. These were bent to each other, as is shown by a positive deviation on one side of the leg surface and a negative deformation on the opposite surface. Such deformations might result from the regular removal and reinsertion of the tuning slides in the normal cleaning process. Depending on the individual tuning slide, these deformations are in general clearly below 1 mm, but can still diverge by up to several hundred micrometres. They are hence much larger than might be expected of any growth in a corroded region during the project, and which might have occurred in the same region.

For all tuning slides showing plastic deformation, the variance comparison will not be suitable for showing any growth in corrosion. Here only very small changes can be expected. This is also a drawback when we come to tuning slides in which no deformation has occurred. The pixel size and the resulting voxel size are with circa 100 µm and circa 150 µm rather coarse. Changes smaller than 200 to 300 µm would not be visible with this method.

Unrolling of tuning slide cylinders As the variance comparison analysis could not be used for a large fraction of the tuning slides due to the deformation issue, all of the tuning slide legs were virtually unrolled and the initial and end states compared. For this, a virtual cylinder was fitted into each tuning slide leg using VG Studio Max, and virtually unrolled (see Figure 4a). The grey value of each voxel along the cylinder surface is thus projected onto a 2D plane. The grey values correlate to the mean attenuation that can be found in each voxel, thus giving an indication as to the composition. In regions where the grey values had changed, the attenuation also had to change. If a region on the image is brighter than the grey vale, this means that the attenuation has increased, and this can only be accounted for by an increase in density and/or additional, higher attenuating material. Figure 4b shows a tuning slide leg before, Figure 4c at the end of the project. In the joint, a clear increase can be identified. As an increase in density seems rather unlikely in this case, the change in the attenuation has to have been caused by additional material with higher attenuation coefficients, most likely some hydrogen component. The hydrogen could be part of corrosion products, but could at the same time also be water. Still, at the time of the second inspection at the end of the project, the instruments had not been played for a couple of weeks and the tuning slides had been removed and stored in a special transport container under dry conditions. This makes the existence of any residual water inside the tuning slides rather unlikely.

Comparison of sections at identical positions We examined more closely those regions where we were able to identify changes between the start and the end of the project by means of changes in grey values. To do this, we compared identical positions in different section planes. Figure 5 shows a comparison between the start and the end of the project in two different sections, using the same tuning slide (HKB 5024.2). Section A, a vertical section through the tuning slide, close to the joint of leg and bend, shows a blistered, porous structure on the right side of the joint. This structure, which is possibly a flawed solder joint, appears as a hollow, empty blister at the start of the project, but is filled to a large extent at the end of the project with highly attenuating material. Section B shows

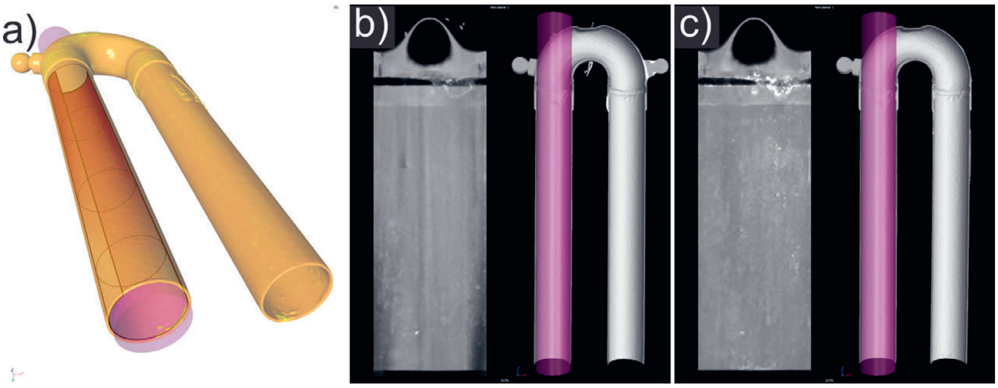

FIGURE 4 Virtual unrolling of the tuning slide legs; a) 3D visualisation of a tuning slide with the cylinder (purple) fitted in one of the legs; b) unfolded tuning slide leg at the start of the project; c) unfolded tuning slide at the end of the project; in the region of the joint a clear increase in higher attenuating voxels is visible.

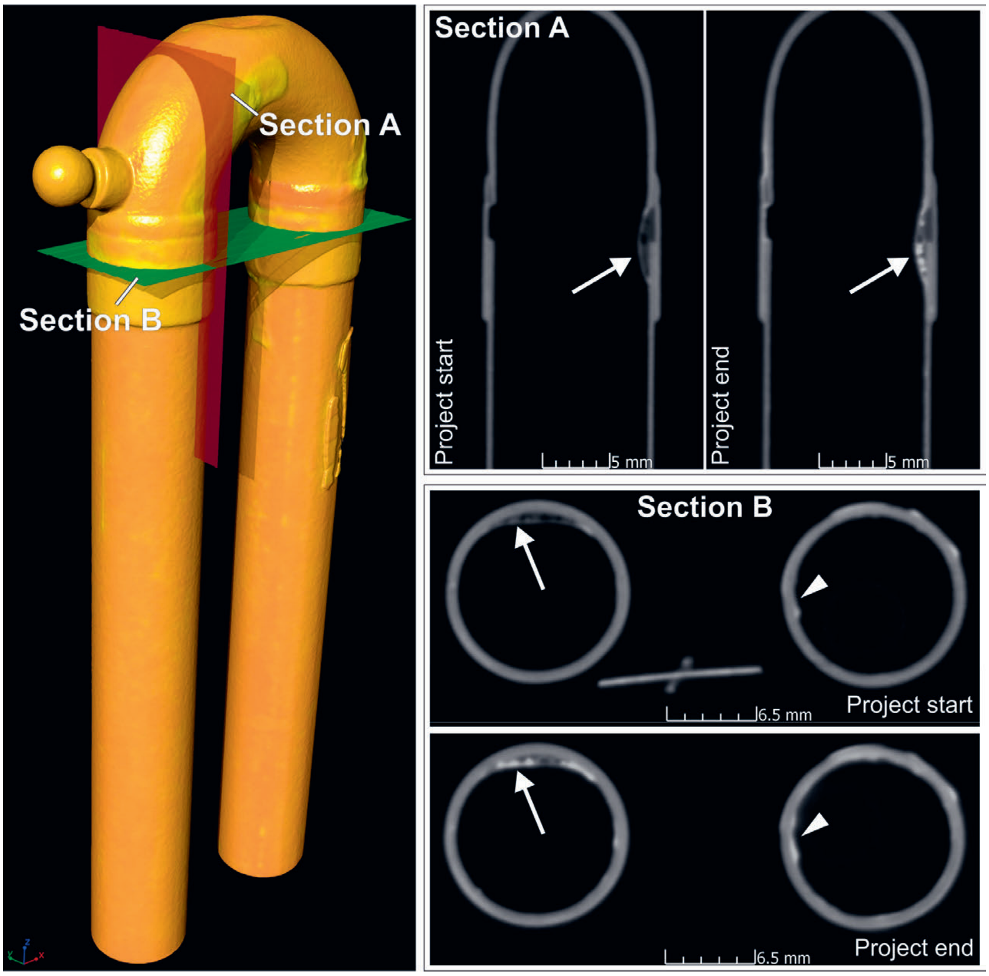

FIGURE 5 Sections of the tuning slide HKB 5024.2; section A shows an empty porous structure (arrows) at the start of the project, which is filled with highly attenuating material by the end of the project. The porous structure can also be seen in section B (arrows); also in section B, we can identify a smaller region with higher attenuation that increased in size between the start and the end of the project (arrow heads).

the same joint in a horizontal section, perpendicular to section A. Here, the blister of solder material appears empty again at the start and partially filled-in at the end of the project. Besides this, there is a small, higher attenuating region in the joint, visible in the other leg. While it is relatively small at the beginning, it is considerably larger by the end of the project. Even though the material in the blister and the joint shows grey values (and hence attenuation coefficients) in the same order of magnitude, it could not be clarified if the materials are identical.

The material in the blister might be some corrosion product containing hydrogen that has accumulated below the surface. Another possibility is residual water that has condensed while playing the instrument. This explanation seems less likely, as all the instruments had been dried and cleaned after the end of the project, and the individual tuning slides were kept in a dry transport container. Another possible explanation is that this highly attenuating material is residual oil or grease that might have been applied after cleaning the instruments.

For the increase in higher attenuating material in the other leg, water seems the least probable candidate. It is more likely that there has been growth in a corroded area, or that there is some residual oil or grease that might have been applied after cleaning. The higher attenuating region increases between the start and the end of the project. This might be accredited to a growth of a corrosion spot that was already present, but whose dimensions were smaller at the first measurement. Another explanation could be that the material represents grease that has been applied after cleaning, and has by chance accumulated in the same spot.

Summary and conclusion Neutron imaging is a non-destructive method that can be used for monitoring long-term experiments on the playability of historical brass instruments, such as the present project. For this, tuning slides from 15 instruments were inspected at the start and the end of the project. It proved difficult to compare changes in the inner surfaces. Many tuning slides showed plastic deformation (bending of the legs of up to 1 mm), which made a clear result in these regions impossible. This was because much smaller changes in dimensions would be expected due to the growth of corrosion layers. The rather coarse voxel sizes of 98 µm and 150 µm respectively allow only for an identification of displacement of the surface due to the growth of corrosion layers in the range from 200 µm to 300 µm upwards. The comparison of the voxel values, which correlate with the attenuation coefficients for the individual voxel, was more successful. In several tuning slides, regions with higher attenuation could be identified whose dimensions increased between the two measurements. Possible explanations are that these spots correspond either to remains of grease or oil applied after cleaning the instrument, or to the presumed growth of already corroded areas.

This project showed that neutron tomography can be used for monitoring long-term changes in cultural heritage objects. By comparing the CT data of several points in time, it is possible to identify and quantify geometrical changes within the range of the spatial resolution (for example plastic deformation, the increase and decrease of wall thicknesses, et cetera) as well as changes in attenuation, which can be attributed to local changes in the elemental composition or density (for example in the formation of different corrosion products, the presence of moisture, the distribution of consolidants, and so on).

Content

To Play or Not to Play

Corrosion of Historic Brass Instruments

Romantic Brass Symposium 4 • Edited

by Adrian von Steiger, Daniel Allenbach

and Martin Skamletz

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HOCHSCHULE DER KÜNSTE BERN
Edited by Martin Skamletz
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Volume 15

Dieses Buch ist in gedruckter Form im Januar 2023 in erster Auflage in der Edition Argus in Schliengen/Markgräflerland erschienen. Gestaltet und gesetzt wurde es im Verlag aus der *Seria* und der *SeriaSans*, die von Martin Majoor im Jahre 2000 gezeichnet wurden. Gedruckt wurde es auf Eos, einem holzfreien, säurefreien, chlorfreien und alterungsbeständigen Werkdruckpapier der Papierfabrik Salzer im niederösterreichischen Sankt Pölten. Das Vorsatzpapier *Caribic cherry* wurde von Igepa in Hamburg geliefert. *Rives Tradition*, ein Recyclingpapier mit leichter Filznarbung, das für den Bezug des Umschlags verwendet wurde, stellt die Papierfabrik Arjo Wiggins in Issy-les-Moulineaux bei Paris her. Das Kapitalband mit rot-schwarzer Raupe lieferte die Firma Dr. Günther Kast aus Sonthofen im Oberallgäu, die auf technische Gewebe und Spezialfasererzeugnisse spezialisiert ist. Gedruckt und gebunden wurde das Buch von der Firma Bookstation im bayerischen Anzing. Im Internet finden Sie Informationen über das gesamte Verlagsprogramm unter www.editionargus.de, zum Institut Interpretation der Hochschule der Künste Bern unter www.hkb.bfh.ch/interpretation und www.hkb-interpretation.ch. Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über www.dnb.de abrufbar.
DOI 10.26045/kp64-6179 ISSN 2700-8681 ISBN 978-3-931264-95-6