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Investigation of the Holy Crown as a Metal Structure

Miklós Barabássy[1*]

[1] Kempelen Academy of Sciences Foundation, Kertváros utca 23., H-1028 Budapest, Hungary
[*] Corresponding author, e-mail: miklos.barabassy@gmail.com

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Abstract

The article analyses the crown of Hungarian kings, a crown of sacral importance, as an engineered metal structure resulting from a technological process. Its composition revolves around two primary components: the cross-strap and the hoop. The cross-strap consists of the actual cross-strap stems and the cross. As for the hoop crown, it comprises the hoop, the diadem (a pediment), and the pendants. The assembly sequence of these parts and sub-parts are described, how the hoop and the cross-strap were aligned and how the sub-parts—the diadem, pendants, and various decorative elements—were assembled and aligned with the primary components. A 3D fully parametric CAD model was used for the analysis. Results show that the eightfold division of the hoop is accurate and that the cross-straps are made with a small degree of inaccuracy, suggesting that they were developed independently. Alignment of the hoop was achieved by asymmetrical cutting, to align with the centerline of the back cross strap stem. The diadem, pendants, and other decorative elements, although fixed to the hoop in a coherent manner, are aligned with the cross-strap. Consequently, the cross-strap emerges as the defining element of the unified Holy Crown, around which all other components are harmoniously aligned.

Keywords

Holy Crown of Hungary, medieval goldsmith's art, artifact metal structures, technology, technic, crowns, cloisonne enamel

1 Introduction

The Holy Crown is the most important witness to the continuity of Hungarian history. This relic (Fig. 1[1]), so important that it was personified, became part of the Hungarian historical constitution and there was a period when it had the highest authority [1]. All Hungarian kings considered themselves the successors of St. Stephen, the first king, and Hungarian kings were only recognized as such if they were crowned with the crown of St. Stephen.

The true origin of the Holy Crown of Hungary remains a subject of debate among historians. Several theories exist regarding its creation:

- Ancient Asian provenance: Some researchers believe that the Holy Crown originated in Georgia, or even further east, in the time before the Hungarian Conquest [2].
- Commissioned by King St. Stephen I: Another legend suggests that the crown was ordered by St. Stephen, the first Hungarian king, specifically for his coronation. This theory implies that the crown was intentionally crafted as a symbol of royal authority and national identity [3].

Fig. 1 The Holy Crown

1 By permission of Szelényi, K. : 2018

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- Byzantine and Latin Origins: The now prevailing official theory is that the Holy Crown consists of two parts: the determining part, the lower part, also known as the "Greek crown", was received by King Géza I of Hungary from Michael VII of Doucas in the 11th century. The upper Latin- inscribed cross-strap was added later, allegedly in the 12th century [4].

More than fifty kings were crowned with the Holy Crown throughout Hungary's history, with the last coronation occurring in 1916. During World War II, the crown was moved to various locations in Hungary, Austria and Germany to protect it from Soviet troops. Following the end of the war, the crown was eventually entrusted to the United States Army for safekeeping. For much of the Cold War, the crown resided in the United States; however, on January 6, 1978 it was returned to Hungary [5].

After the return of the Holy Crown, the Minister for Culture established the Crown Commission[2] with the specific task of scientifically studying the Crown. Simultaneously, a small team of engineers led by Professor Csaba Ferencz [6] and a group of goldsmiths led by Lajos Csomor conducted direct measurements on the Crown and published their findings [7]. These meticulous investigations highlighted crucial details. However, their conclusions were overruled by the Crown Commission,[3] which primarily consisted of social scientists [8]. The Commission favoured a historical perspective rather than a technological one. Later, two additional goldsmiths were included in the inquiry, but their activities were restricted to answering specific questions posed by the Commission [9]. Despite these limitations, their work yielded significant findings and observations, contributing to the overall scientific understanding of the Crown, albeit not in a comprehensive manner.

In 2000, the crown was transferred from the Hungarian National Museum to the Parliament building, and thus further direct examination is subject to the approval of the so-called Holy Crown Board.[4] Extracts from the Board's minutes were, until 2010, in the public domain. The 2006 minutes state the conditions on what is required to authorize a direct examination of the Crown [10]: "experts must give a prior opinion ... in writing on the need for an X-ray examination of the Holy Crown, the justification for and possible results of such an examination, the nature of the procedure and its possible risks".

Based on the recommendation of the President of the Hungarian Academy of Sciences, a committee of experts under the chairmanship of Ernő Marosi was asked to give a scientific opinion on the matter. The group did not do so to date.

Hence, the aim of the present work is to reconstruct the Hungarian Holy Crown from a technological perspective and provide a proof on how it was ensembled. The Holy Crown itself stands as the sole indisputable, objective evidence of its establishment; and throughout the manuscript it shall be referenced as a metal object rather that a holy, mystical object. From an engineering perspective, the initial task involves clarifying the investigation's scope and determining how further objective insights can be obtained on the origin of the Holy Crown. To achieve this, one must meticulously assess the available data, narrowing down the focus to what can confidently be stated.

For this work the following documents and sources were examined, and with their help a 3D fully parametric CAD model was built:

- Minutes of the Crown Commission appointed in 1978-1986 [8]
- Various objective descriptions of the crown, referred to later in the text
- Tables of measurements by Lajos Csomor and the goldsmiths [7]
- Two series of photographs by Károly Szelényi[5]
- Parliament's own films and photographs by György Bence Kovács[6]

2 The Crown Commission was established by Pozsgay, I. Minister of Culture, on 02 February 1978. Its members are historians György Székely, Ferenc Fülep, György Györffy, Gyula László, archaeologists Tibor Kovács, Zsuzsa Lovag, art historians Zoltán Kádár, Éva Kovács, Pál Miklós, and restorer Joachim Szvetnik.

3 Minutes of the Crown Commission from 16 December 1983 : "The Commission requests the Minister of Culture to ensure that, in accordance with the 1978 regulation, only books revised by the Crown Commission may be published, and to intervene with the Directorate General of Publishing to ensure that only such books may be authorised for publication. The Commission asks that the same be done with regard to TV."

4 Holy Crown Board: President: President of the Republic, Members: Prime Minister, President of Parliament, President of the Constitutional Court, President of the Curia, President of the Hungarian Academy of Sciences

5 By permission of Szelényi, K. : 2018

6 The Parliament, with the permission of Such, Gy., Director General, for the publication of Barabássy, M. "Holy Crown of Hungary an engineer-ing perspective", published by Pen Club, 2020.

Ultimately, the main objective is to verify that all the necessary data are available to reconstruct the technological process. With knowledge of the technological process, it is possible to satisfy the expectations of the Holy Crown Board, to open the way to in-depth direct investigations that could ultimately lead to knowledge of the establishment of the Holy Crown.

2 Description of the structure of the Holy Crown

When an observer closely examines the Holy Crown, particularly using the basic method of non-destructive examination (visual inspection), a distinct structural division becomes evident. The crown comprises at least two main parts:

1. The lower hoop section, which could be regarded as a crown on its own, and which features intricate Byzantine enamel figures and is consequently referred to as the Greek crown[7];
2. and the upper vault, however, lacks standalone functionality and is aptly named "cross-strap" due to its distinctive shape.[8]

2.1 Observed differences between hoop and cross-strap

Contributing to the overall understanding of the crown's assembly, it is important to examine the differences between the hoop and the cross-strap.

a) The hoop contains Byzantine enamel images with Greek inscriptions; while the cross-strap contains Latin inscriptions

b) The cross-strap of the Holy Crown exhibits intricate adornments across its entire surface: It features filigree, delicate beads, and tiny drop-shaped gemstones. Additionally, each strap stems two enamel plates adorned with Latin inscriptions (as depicted in Fig. 2). In contrast, the hoop is less ornate, although the enamel images on it represent the pinnacle of Byzantine enamel craftsmanship from that period (as shown in Fig. 3) [11].

c) The cross strap of the Holy Crown is optically judged to be made of a purer gold alloy, while the hoop ring is composed of a less pure gold alloy.

d) Unfortunately, this distinction cannot be discerned from photographs alone, but it has been described by several crown observers [12]. Surprisingly, no composition analysis has been conducted on the Holy Crown, despite the availability of non-destructive or minimally invasive methods [13].

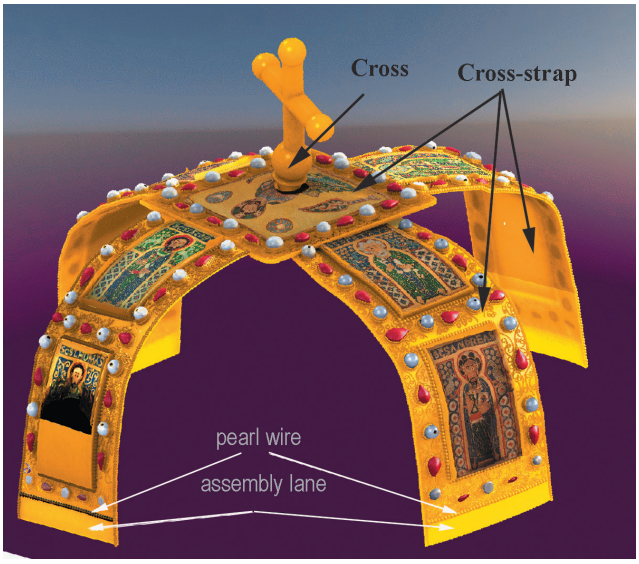

Fig. 2 The cross-strap

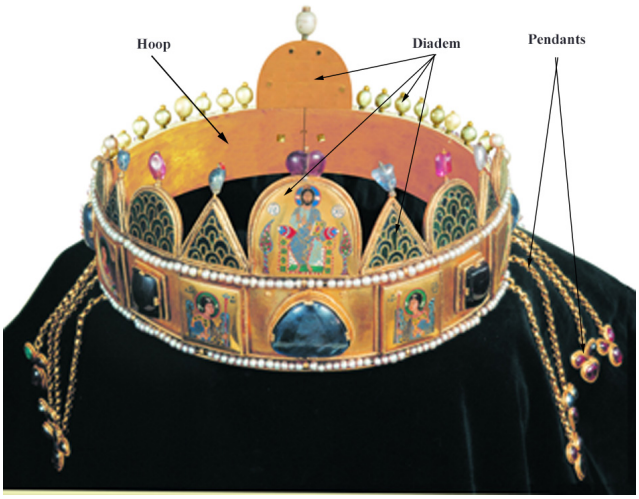

Fig. 3 The Greek crown

e) The hoop mounted diadem and pendants together give the impression of a functional crown on its own [14] (Fig. 3).

f) The two parts are fixed together with rivets [9]. The enamel on the hoop diadem is crafted using the plique-à-jour[9] technique, which involves creating eight triangular and semicircular cutouts. This technique is both rare and unique. Notably, it distinguishes itself from the Byzantine and Western cloisonné enamel techniques employed elsewhere on the crown[10] [15].

7 Byzantine enamel: Here we consider Byzantine enamel to be the enamelled bust images and the image of Christ with Greek inscriptions.

8 Latin enamel paintings: the Latin inscriptions. Other features: banded eyes and framing in a vaulted frame.

9 Plique-à-jour enamel: an enamel without a back plate. The enamel receiving cavity is formed by the compartments (cloisonnes).

10 Enamel cloisonne : A recess (recipient) in a plate in which the different coloured glass melts are separated by strips (cloisonnes) set at the edges. No significant difference between Eastern and Western technology.

2.2 Differences based on technological examinations

g) The gemstone sockets in the hoop were created using conventional hard soldering, with the addition of solder. [16] During this process, some solder dripped in some areas. In addition, the gem sockets were placed asymmetrically and tilted (as shown in Fig. 4)

h) The cross-strap is meticulously assembled from five parts using very high-quality diffusion soldering [17–19] (Fig. 5). In contrast, the soldering on the hoop ring exhibits lower quality craftsmanship.

i) The central image of Christ on the diadem is slightly shifted to the left when viewed from the front. Upon closer observation, it is noticeable that it is positioned just in front of the first stem of the cross strap (as depicted in Fig. 6a)).

j) Further observations reveal that the ring holding the bead string below the image of Christ is also aligned with the axis of the front stem of the cross-strap (as depicted in Fig. 6a)). Additionally, the socket of the diadem on the opposite side of Christ, specifically the socket of Michael VII Doucas, shifts in the same direction as Christ (clearly visible in Fig. 6b)). Interestingly, this socket is also directly in front of the back stem of the cross-strap, maintaining alignment along its axis of symmetry. Furthermore, the first ring holding the pendant below the image of Michael the Doucas also lies on the same axis of symmetry.

Fig. 4 Incorrectly placed gemstone socket (skewed, sideways, and rough soldering)

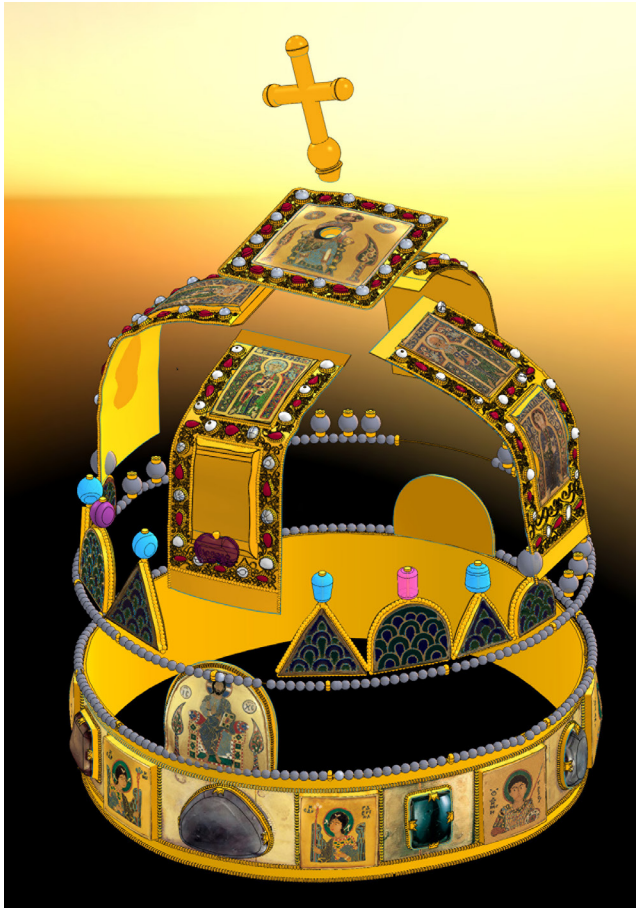

Fig. 5 Exploded view of the model

Social-scientifically, the observations from points a) to f) appear to lend support to the two-crown theory. According to this theory, the lower part of the crown could have originated from a Byzantine-made crown, while the cross-strap was added later. However, to date, no concrete evidence has been presented to substantiate this hypothesis.

While a technological approach does not inherently involve a criticism of the social-scientific theory, it does provide an explanation also for points g) to j), which the social-scientific theory cannot explain. Although these have been described previously, in the lack of a comprehensive and satisfactory explanation, they could not be used to justify any theory [20].

3 Reconstruction of assembly

3.1 Creating a CAD model

Since technical knowledge of the Holy Crown was scars, the first step was to create a 3D fully parametric CAD model. Difficulties included crafting intricate details such as filigrees and tiny sockets, which made this a lengthy process.

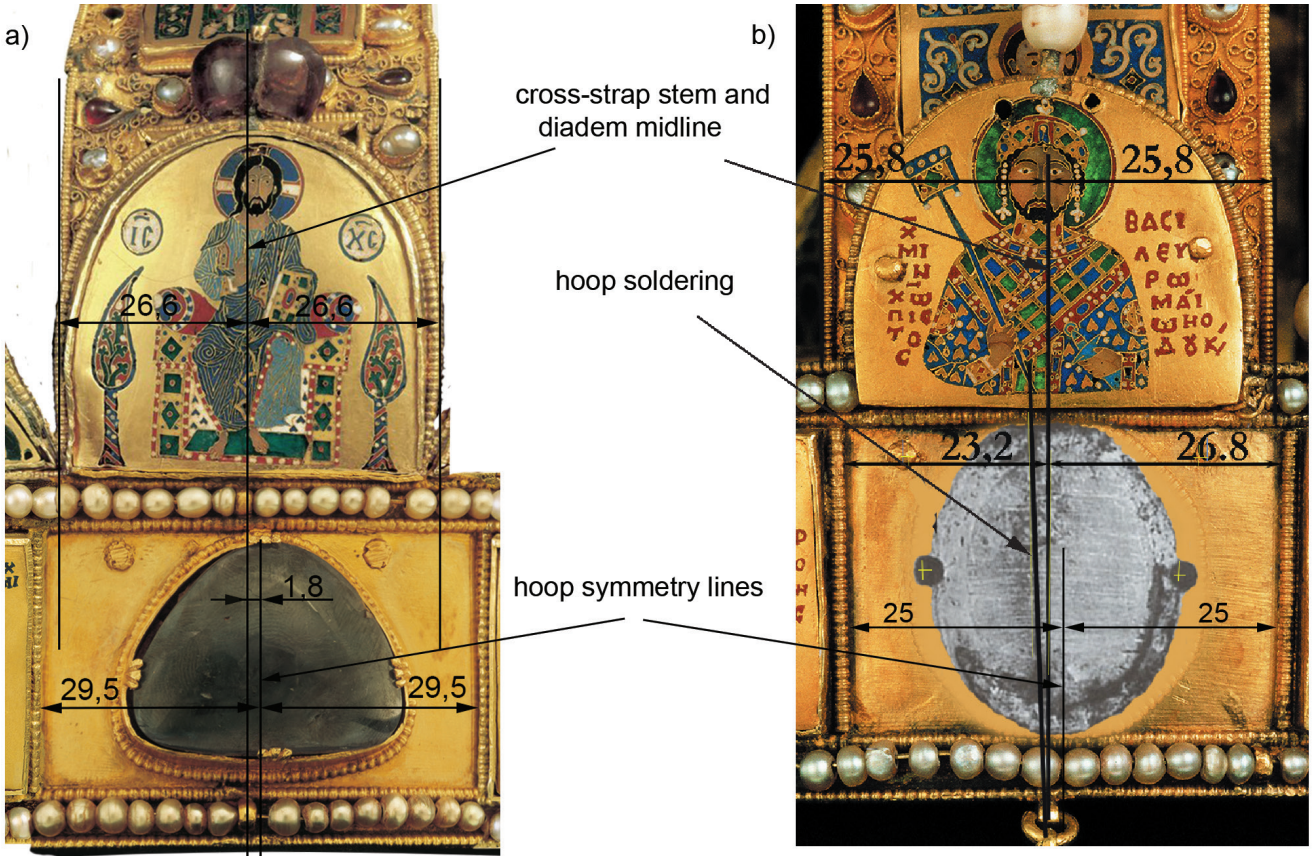

Fig. 6 The asymmetrical positioning on the hoop and the alignment with the cross-strap stem; a) Position of the Christ socket; b) Position of the Michael VII socket.

However, the attention to detail, proportions, and dimensions achieved with presenting an existing object as a CAD model align more closely with manufacturing rather than design.

Data used for the modelling included data provided by Lajos Csomor, partly measured to an accuracy of 0.1 mm [12] and a series of high-resolution photographs obtained from Károly Szelényi. Additionally, a photograph where the back octagonal gemstone socket had been removed was used [21].

Initially, the dimensions of the photographs were adjusted to match the measured data. The modelling process commenced with basic spline splitting of the hoop. Subsequently, construction proceeded based on the hoop dimensions. Gradually, the following components were completed: the hoop, the horizontal division and decoration of the hoop; the four stems of the cross-strap; the cross-strap roof plate; the diadem and finally the cross. The exploded view of the finished model is depicted in Fig. 5.

3.2 Observations with the help of the CAD model

Methodologically, when analyzing the structure of the Holy Crown, factors such as the style of decorations, the enamel designs, the time or place of its manufacture hold no significance. What truly matters are the division of the hoop, which is precise, the diadem and other decorative elements that belong to the hoop but are aligned with the stems of the cross strap.

With the help of the developed CAD model, the following can be stated concerning the fitting of the hoop to the cross-straps:

- The hoop ring is divided in such a way that the front and back gem fields are larger than the other gem fields. This arrangement implies that the hoop ring was likely crafted as part of a crown. The dimensions are illustrated in Fig. 6. Notably, the hoop ring's shape is only slightly elliptical and remains close to a circular form (Fig. 7).
- The Doucas plate is flat. The Kon and Geobitzas enamel plates are not convex, like the Christ and the remaining six enamel plates on the hoop, which conform to the hoop's shape and are convex. Consequently, these 7 enamel images (Fig. 8) were either made on the current ring or were transferred from a ring of a similar size to the current ring.
- When examining the enamel socket and a gemstone field on the hoop, we notice a meticulous division. Specifically, if we treat the two edges of the front

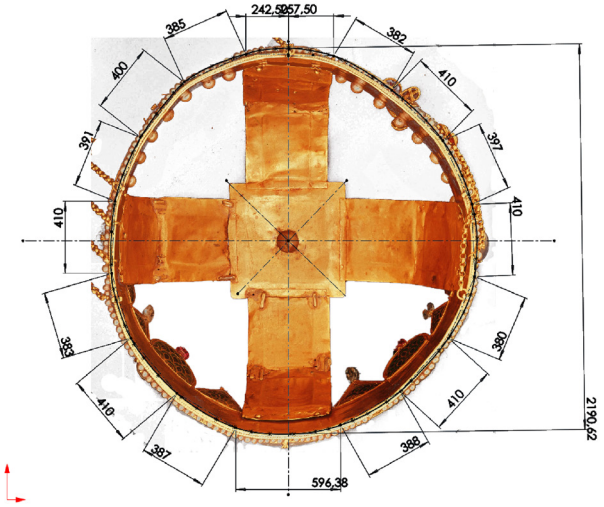

Fig. 7 Divided crown hoop

Fig. 8 Christ, Doucas, Cosmas plate shapes

field as a single unit, we observe a 3–3 division on the sides. However, it's worth noting that the Kon socket deviates slightly by being 1 mm forward. The overall division into eight segments (as depicted in Fig. 7) follows a characteristic medieval construction pattern.

- The cross-strap stems were initially decorated one by one with filigree and sockets. These were then soldered to the cross-strap top plate. The process involved securing and positioning the stems to the roof plate using rivets, followed by the soldering step. The riveting shown in Fig. 9 indicates that the stems were soldered together already decorated but lacking enamel and jewels. Had they not been manufactured in this order, the rivet heads would not be visible from the top view.

Fig. 9 Filigree damage: roof plate and cross strap stem joined by rivets

- The cross-strap stems were skillfully aligned in a single direction, forming a straight line. However, their alignment with the cross exhibited some inaccuracy. This deviation can be observed and quantified in Fig. 7. The arc length between the right and back stem's center line end is 4.7 mm greater than the arc length between the left and back stem's center line end.
- Alignment of a cross strap to a hoop with a pitch of 8, is only possible with two opposite stems. The position of the other two stems can no longer be influenced. The selected direction to attach the cross-straps to the hoop was at the side, and not at the front and back; potentially because of the width of the front and back gemstone fields, which are larger than the side ones. The other two stems are not in line with the symmetry line of the hoop. But these minor inaccuracy goes largely unnoticed.
- The cross-strap and the hoop ring were crafted independently. While the hoop ring exhibits precise division but seems otherwise as a half-finished piece. The cross-straps on the other hand, are very detailed and high quality, however the angles between the stems are uneven. Had they been designed together; they would have aligned seamlessly.
- With the help of a photograph as shown in Fig. 10, where the back octagonal gemstone socket was removed, it became evident that the ends of the hoop fit together superficially, and an original oval gemstone remains can be authenticated. The line formed by these ends is off-center, shifted to the left (as depicted in Fig. 11). The soldering is done in one point and does not fill the gap between the ends. In the early 17th century, the oval gemstone was

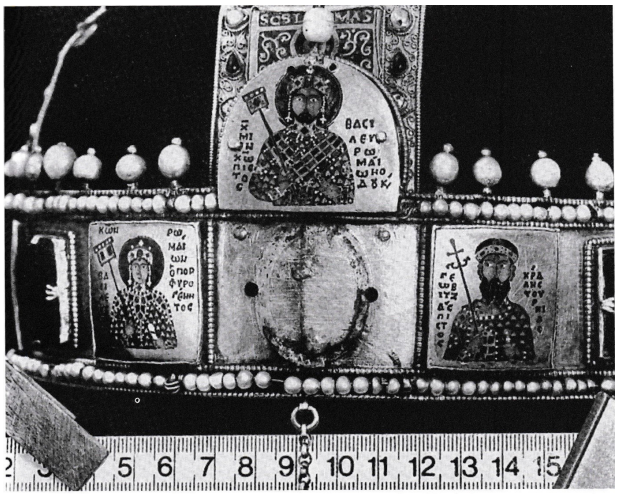

Fig. 10 Holy Crown with back gemstone removed [22]

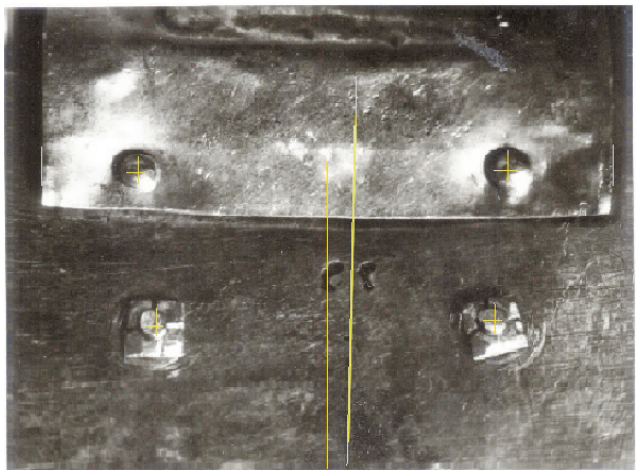

Fig. 11 The ends of the hoop from the inner side [8]

re-placed by an octagonal one. The inner photograph (also Fig. 10) reveals that the ends were first drawn together by two small holes. This was covered by the spot solder from the outside, without the solder flowing into the holes and between the ends. Notably, the new gemstone socket and rivets are not centered in relation to the line formed by the ends.

For improved clarity on the positioning of the front and back sockets and the gemstone fields, the latter added octagonal gemstone was removed (leaving the original oval shape). The position of the back socket–the Doucas socket–in relation to the gemstone field of the hoop is depicted in Fig. 6b). Similarly, the position of the central socket–the Christ socket–in relation to the hoop is shown in Fig. 6a). In both cases, the symmetry axis of the gemstone fields, the solder line at the back of the hoop, the pendant ring, and the rings holding the bead string, all shift to the left relative to the symmetry axes of the sockets. Importantly, these shifts align uniformly with each other—not along the centerline of the gemstone fields—but rather along the centerline of the cross-strap stems.

- The soldering is done in one point and does not cover the gap between the ends.
- In the early 17th century, the oval gemstone was replaced by an octagonal one.
- The photograph on the inside (Fig. 11) shows that the ends were first drawn together by two small holes. This was covered by the spot solder from the outside, without the solder flowing into the holes and between the ends. You can clearly see the new gemstone socket, the rivets and the fact that they are not centered in relation to the line formed by the ends.
- For a better understanding, I have removed the octagonal newly mounted gemstone from the back photograph to show more clearly the position of the back socket, the Doucas socket, in relation to the band ends. Fig. 6b).
- The position of the Christ central socket, shown in Fig. 6a)
- In both figures it can be seen that the symmetry axes of the sockets in relation to the symmetry axis of the gemstone fields, the back of the solder line of the hoop ends, the ring holding the pendant, and the front of the rings holding the bead string are shifted to the left in the same direction. But importantly, these slips are equally aligned with each other, not on the centerline of the gemstone fields, but on the centerline of the cross-strap stems.
- Methodologically, when studying the structure of the Holy Crown, the style of the decorations, the enamel designs, plays no role at all. Neither does the time or place of its manufacture play a role. What is decisive, however, are the three parts: the position of the gemstone fields of the hoop ring and the cross-strap stems, together with the marked and slipped elements. To summarize, although all the elements of the diadem, the front rings holding the bead set and the pendants are attached to the hoop by an unbreakable bond, they are not aligned with the symmetry of the hoop, but all with the cross-strap stem.

3.3 Possible ways of assembly

The cross strap is a distinct and separate piece. Once completed, its only feasible alignment involves folding the stems either inward or outward. Curiously, the intended 90° angle between the stems was never achieved–neither during manufacturing nor during assembly.

The pitch of the hoop ring was achieved with a tolerance of 0.1 mm, except for the Kon socket, which has a deviation of 1 mm. Based on the exact pitch of the hoop ring, we can infer that the widths of the front and back gemstones were likely equal. Furthermore, it's confirmed that the back gemstone field of the hoop was meticulously cut along the centerline of the back cross-strap stem (as detailed above and shown in Fig. 6b). If we sum the measured data to the right and left of the axis of symmetry below the Christ gemstone, we find that the left side of the Christ is 4.7 mm shorter. The 3.6 mm discrepancy, as indicated in the Fig. 6b), results from the 1 mm forward slip of the Kon enamel socket.

By cutting out a section from either side of the back symmetry axis of the hoop, its overall diameter changes, but the pitch remains consistent! However, in the case of the Hungarian crown, the cut wasn't made directly along the axis of symmetry. Instead, it was somewhat sideways, resulting in the shortening of only the back left hoop quarter. However, it is noteworthy that the measure of this back left quarter of the hoop arc is equal to the measure of the angle between the left and back cross-strap stems. When fitting together two pieces–one is accurate and one slightly off–the result necessitates precise adjustments, and this has on the hoop: the asymmetrical cut serves as confirmation that the fitment was indeed tailored to the finished cross strap.

The diadem consists of two main units: the front side is attached to the central Christ socket, with 2 to 2 triangular and semicircular sockets on each side. On the nape side, the Doucas socket stands alone. The positioning of the diadem elements on the hoop is intricately tied to the placement of the Christ and Doucas sockets. The position of the frontal part of the diadem, relative to the axis of symmetry of the Christ socket, is equal on the right and on the left side (tolerance 0,1 mm). However, this alignment is a deliberate choice. The goldsmith could have easily aligned it with the axis of symmetry of the hoop ring, but instead, it was aligned with the cross-straps, so the construction of the diadem was done after the cross strap and hoop ring assembly had been completed.

Notably, representatives from the goldsmiths' group (J. Péri and L. Papp) believed that the frame of the diadem's sockets was formed from the hoop ring, implying a single material composition [22]. Although photographic evidence cannot confirm this definitively, it has been assigned significant value without substantial merit. Whether it was made from a single material or applied to the hoop through fitting and soldering, the diadem was meticulously shaped–not to fit the hoop but to harmonize with the cross straps.

4 Conclusions

A technical examination of the Holy Crown reveals that the main defining part is the cross-strap. The alignment of the hoop ring is meticulously tailored to match the cross strap. The hoop ring could have been made before the creation of the cross-strap (either as a re-used piece), at the same time or afterwards – this is not in question here. However, the fitting of the diadem, the front bead row support rings, the pendants and the large gemstone socket under the back of the nape could only occur after the cross straps and hoop ring were securely fitted together.

While structural studies do not definitively pinpoint the age or place of assembly, they rule out the possibility of a hoop crown (Byzantine crown) to which the cross-strap was subsequently attached. On the contrary, they support the cross-strap as the defining element of the crown.

In summary, although all diadem elements–the front rings holding the bead set and the pendants–are securely attached to the hoop, their alignment does not follow the hoop's pitch but instead, they align uniformly with the cross-strap stems. Consequently, the cross-strap emerges as the defining element of the unified Holy Crown, around which all other components are harmoniously aligned. Further studies are needed to strengthen the evidence, including:

- a 3D-HD computer modelling, that can refine dimensions, assess technical details, and explore repairs and
- an XRF material analysis, that could identify which crown parts were crafted simultaneously in the same workshop.

These investigations may pave the way for assessing the crown's condition, identifying any alterations, devising a restoration plan and further examining the crown without necessitating additional inspections until further modifications are made.

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