Tomography applied to the study of 17th-century clockmaking techniques: the case of the Simon Le Noir mechanism

Augustin GOMAND

AFAHA regional meeting – 3 December 2023

Projet Simon Le Noir

LMPS

ZEISS

The Simon Le Noir Project

- Project initiated in October 2020 following the discovery of a mechanism signed Simon Le Noir (seen from the back on the figure at right)
- This mechanism presents many specificities that makes it quite different from the first French pendulum clocks (the *pendules religieuses*) and it seems rather to belong to the Renaissance style & era
- Anecdote reported in a manuscript by Claude Raillard (~1720): Simon Le Noir would have been the first to apply the pendulum in France according to his son, Jean-Baptiste
- Main objectives of the project:
  - Detailed analyses of the mechanism from a technical & stylistic point of view
  - Historical researches on Simon Le Noir and the first pendulum clocks
  - Formulation of hypotheses on the place of the studied mechanism in the history of clockmaking
- First articles published in *Horlogerie Ancienne*, June 2022 [1] & June 2023 [2]
- Website to follow the work in progress: https://agomand.github.io/asln/en
- Other publications to follow in 2024

[1] [1] A. Gomand, *Simon Le Noir et l'application du pendule aux horloges : une histoire parallèle ?*, Horlogerie Ancienne, 91, June 2022, pp.16-44
[2] [2] A. Gomand, *Compléments dans l'affaire Simon Le Noir*, Horlogerie Ancienne, 93, June 2023, pp.16-42

Status of the project

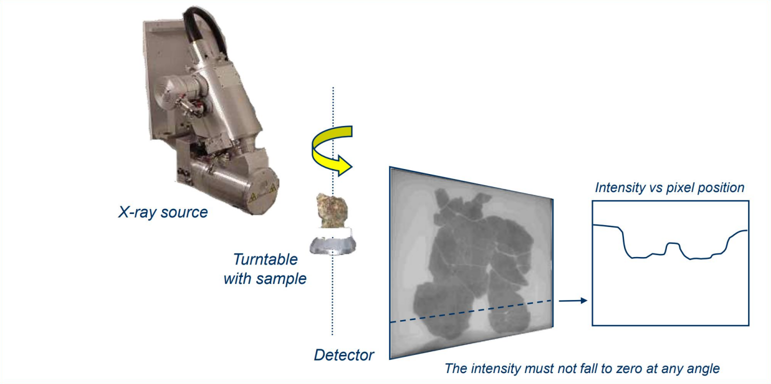
- Researches on Simon Le Noir and the first pendulum clocks:
  - source of the anecdote identified → Claude Raillard treatise manuscript from ~1720
  - potential link between Le Noir and the Polish scholar Tito Livio Burattini, one of the first to get a Coster clock as soon as they were produced in 1657 + inventor of pendulum clock prototypes
- Researches on the history (background) of the mechanism:
  - sale of Leroux collection in 1896 → the clock is described when it was still complete
  - exhibition from the *Union Centrale des Arts Décoratifs* in 1880 → the clock was exhibited in the *Musée Rétrospectif*, as mentioned & described in the exhibition inventory
  - recent story of the mechanism: probably stored in a garage for some decades
- Deep analysis of the authenticity of the mechanism through several means:
  - stylistic approach: comparison with the first pendulum clocks & with Renaissance clocks
  - metallurgical approach: analysis of the gilding / steels / brasses
  - technical approach: do all the parts of the mechanism are built in accordance with the techniques and standards of the 17th-century clockmaking?

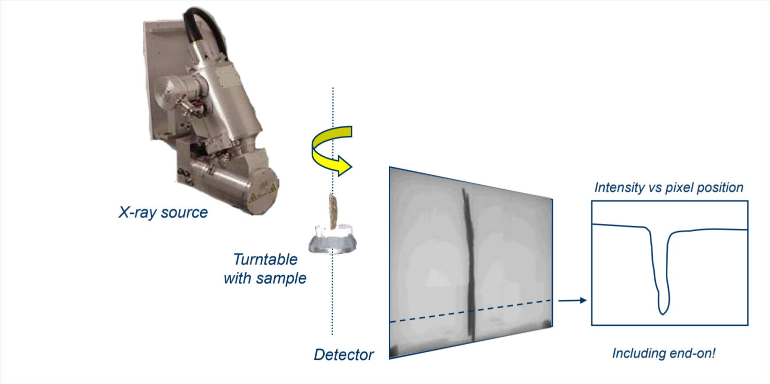
  → **this point has to be refined**

Tomography in a nutshell

- Difficulty: most of the assemblies are no more visible when the parts are finished & gilded
  → need to check how it looks like *inside* the parts & materials with **X-ray tomography**
- Principle:

1. The object is fixed on a rotating support
2. Successive X-ray scans are done with a small rotation of the support after each scan
3. All the scans are post-processed with a computer to build a 3D model of the object

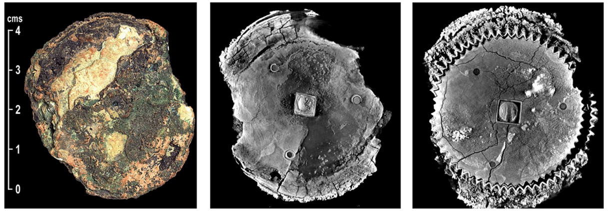


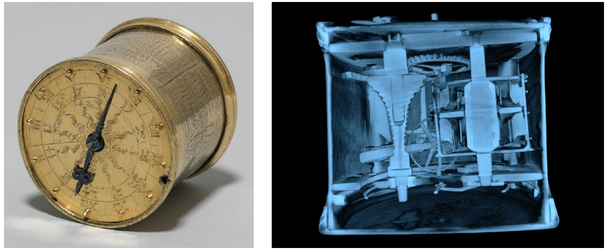


Figures: [3] A. Ramsey, *X-ray Tomography of the Antikythera Mechanism* (Kerastari, 13 June 2012), p.28 & p.30

Tomography and horology

- Technique frequently used in industrial processes
- Several applications in archaeology (*e.g.* the analyses of the Antikythera mechanism, *cf.* figures at the top [3])
- Technique only applied a few times to horological topics:
    - scan of the so-called “Petrus Hele” watch in 2013 [4]
    - 7 primitive watches scanned for the exhibition dedicated to Peter Henlein in 2014
    - other scans for private collectors (*cf.* pictures at the bottom [5])
- Technique mostly used to study the authenticity through the assemblies / alignment of the wheels / previous repairs (bushes) / *etc.*



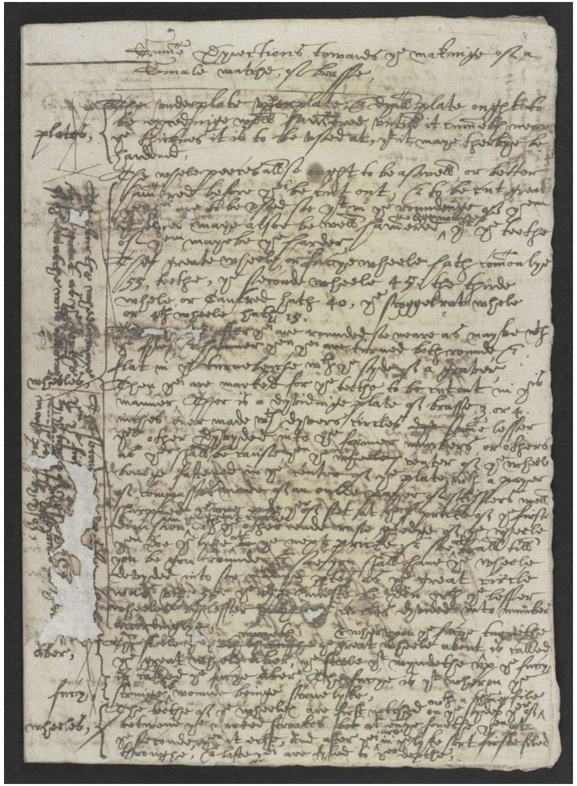


[3] [4] T. Freeth *et al.*, *A Model of the Cosmos in the ancient Greek Antikythera Mechanism*, Nature Scientific Reports, 11, March 2021
[4] [5] J. Ehrt, *Ein Mythos auf dem Prüfstand - Die Untersuchungen an der sogenannten Peter Henlein-Uhr des Germanischen Nationalmuseum Nürnberg* (Restaurierungsatelier Jürgen Ehrt, 2021) – photographies from https://artsandculture.google.com/story/LAXxeqppGOtCLA
[5] [6] https://www.renaissanceuhr.de/uhren/renaissanceuhren/burgunderuhr/

Bibliography used

- We try to work as much as possible with **primary** sources, *i.e.* documents from the 17th & 18th centuries (treatises, inventories of clockmaker's workshops, manuscripts…)
- These documents are scarce and for most of all more recent than the mechanism (beginning / middle of the 18th century)
- One particular document proved to be essential for our study: the manuscript discovered in the papers of the scholar John Evelyn [6] of which the transcription was published recently in the *Antiquarian Horology* [7]

  → in this exceptional document are described in detail the making of almost all the components of a watch from the first half of the 17th century as well as several tools, metallurgical techniques, tricks, *etc.*



[6] [7] British Library: Add. MS 78425 – Evelyn Papers. Vol. CCLVIII, fol. 8 recto - 14 recto

[7] [8] D. Thompson, *'Summe Dyrections towards the makinge of a smale watch, of brasse' – A guide to watchmaking techniques in the seventeenth century*, Antiquarian Horology, 44-2, June 2023, pp.179-206

Tomography at the LMPS

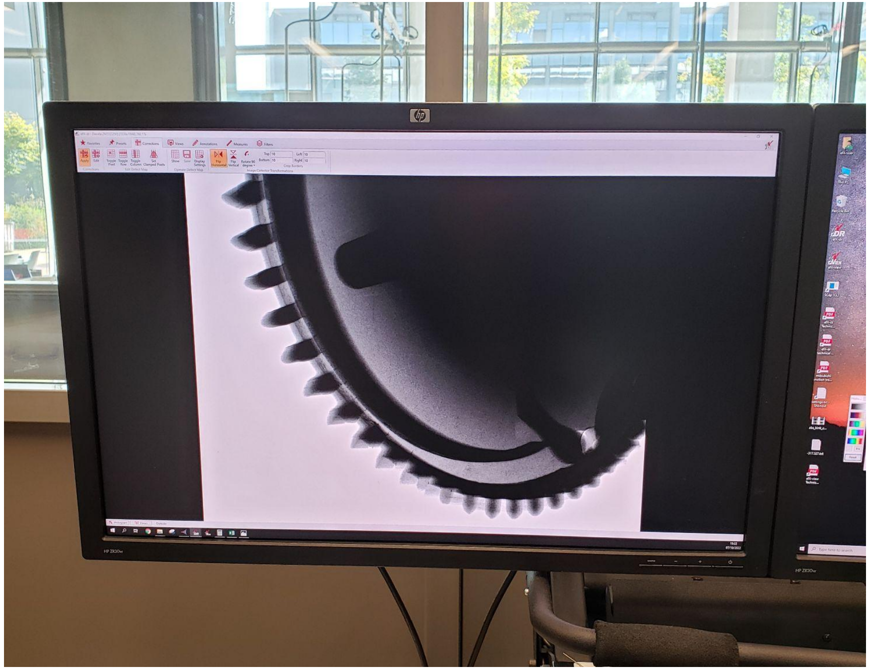
- First scans performed at the LMPS of the ENS Paris-Saclay (front-plate, back-plate & fusee wheel)

The back-plate wrapped before being analyzed

The LMPS tomograph (NSI X50)

Tomography at the LMPS

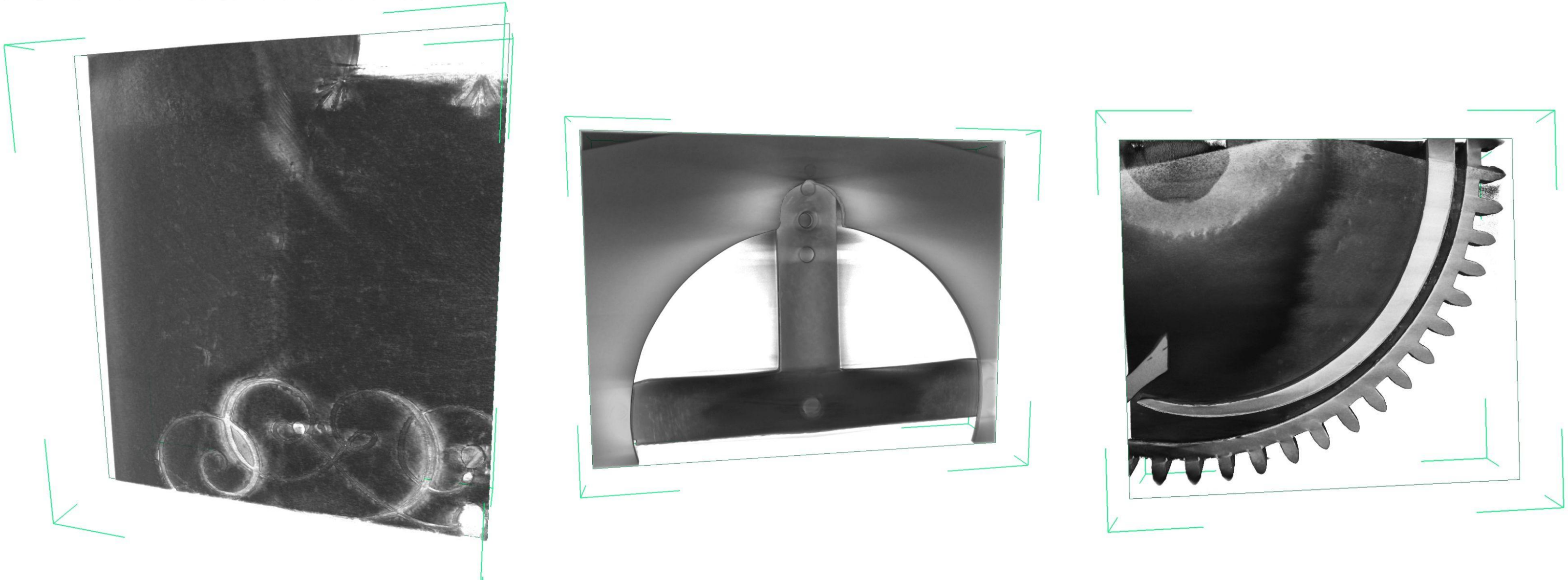
Analysis of the fusee wheel



X-ray view of the fusee wheel

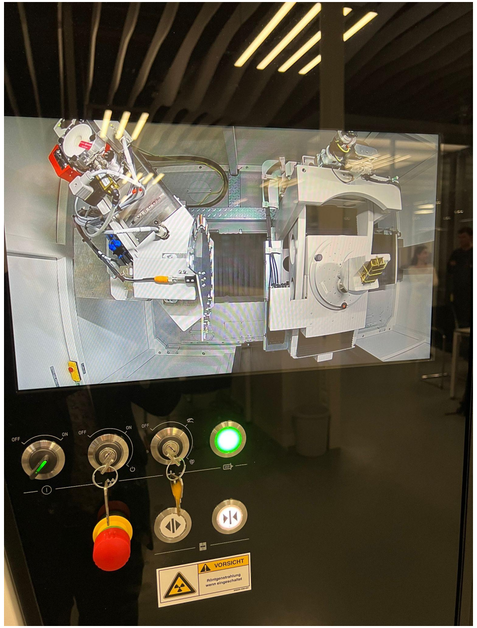
Tomography at the LMPS

- Reconstruction of the different parts, from left to right: back-plate, T-shaped bridge from the front-plate, fusee wheel

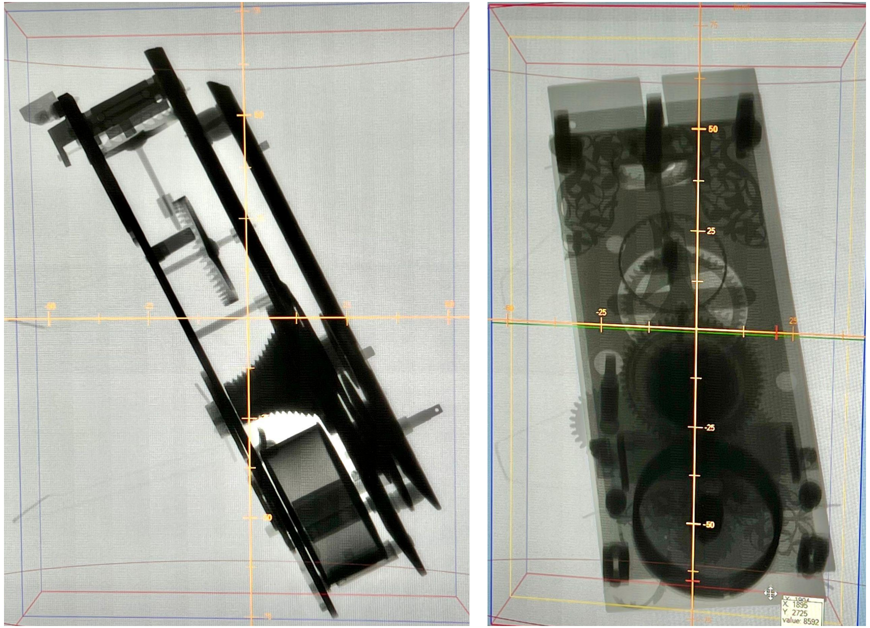


Tomography at Zeiss

- Complementary scans performed by Zeiss → **the mechanism was scanned in its entirety**



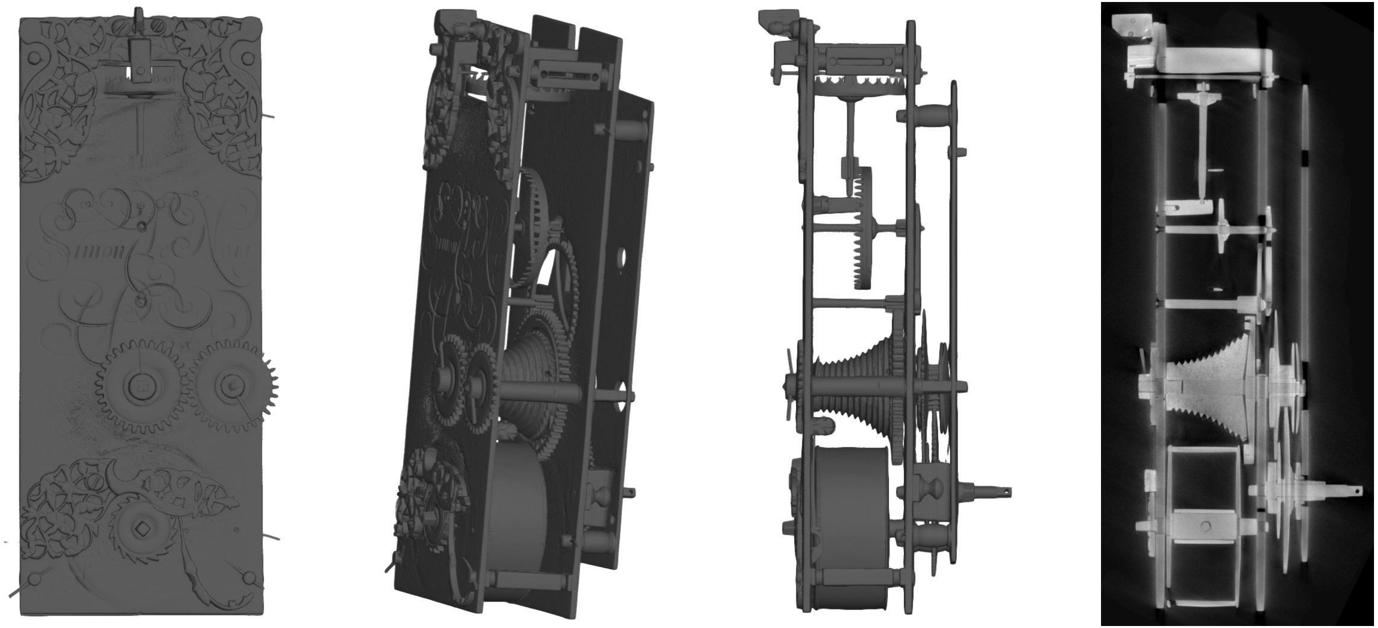
The mechanism in the tomograph while being analyzed



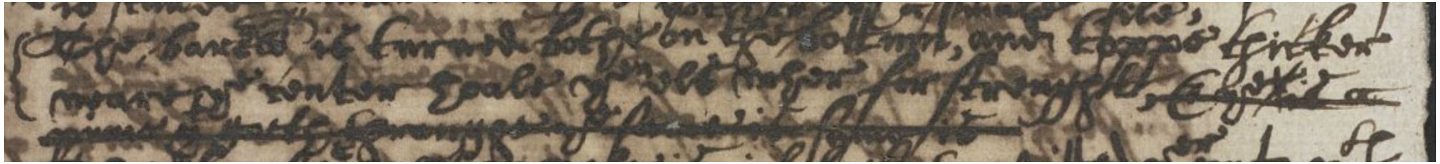
2 X-ray views of the mechanism

Tomography at Zeiss

- Final 3D reconstruction of the mechanism (cut view at right)



Thickness of the plates



- barell,
  The barell is turned bothe on the bottom, and toppe thicker neare the center hoale then else wher for strength, ~~and ther is a pinne that goeth throughe (same is same is)~~ [8]
- *barrel,*
  The barrel is turned on the bottom, and the top ***thicker near the center hole than anywhere else for mechanical strength*** *[...]*

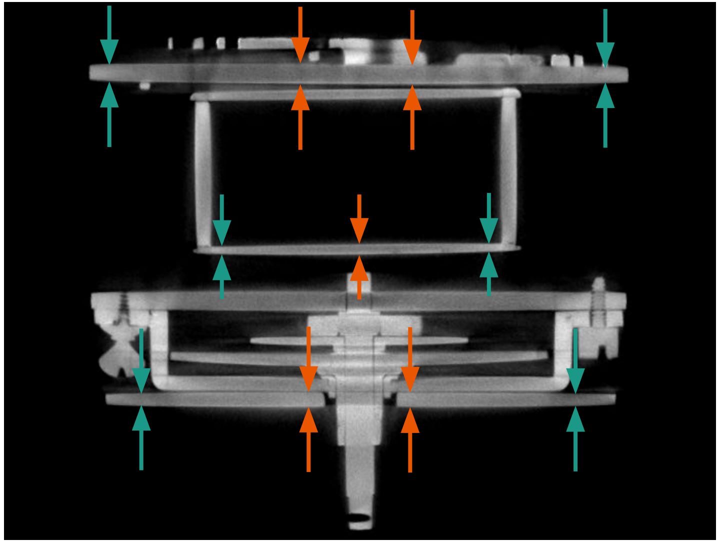
[8] [7] Evelyn papers, folio 10 recto

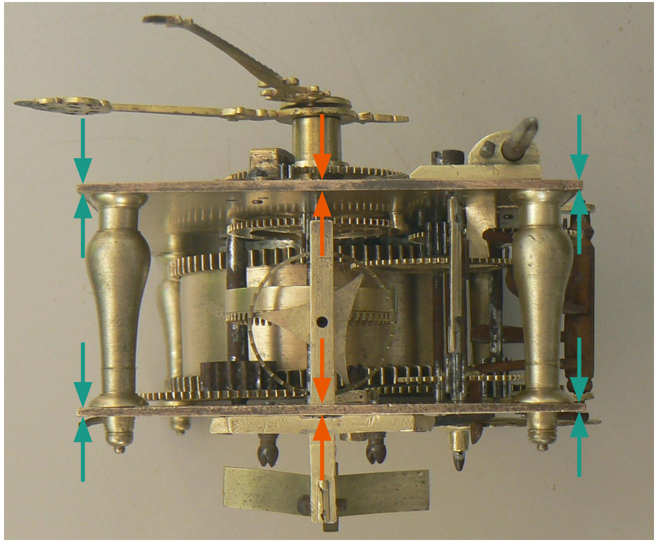
Thickness of the plates

- One can notice that almost all the parts made from plates (front-, back- & false-plate, wheels, drums, *etc.*) are thicker in the center than at the ends.

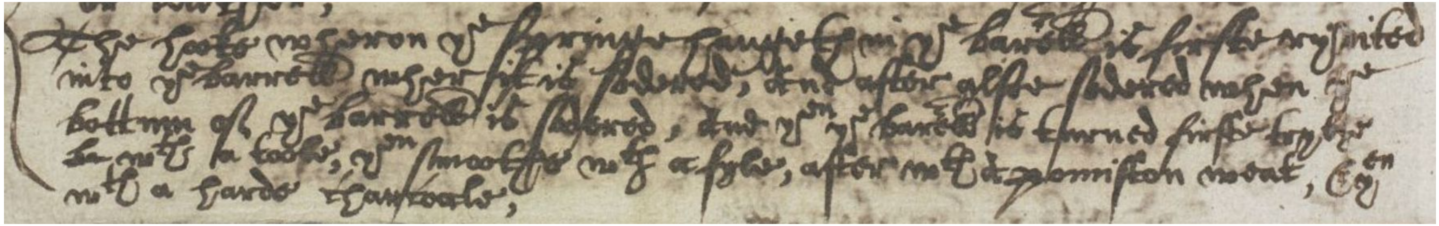
→ **the thickest areas are the ones where there are most of the friction & forces**

→ this feature is found on all other clocks & watches from the same era (*e.g.* below at right, a mechanism from Isaac Thuret c.1670-75)





Manufacturing and assembly of the barrel

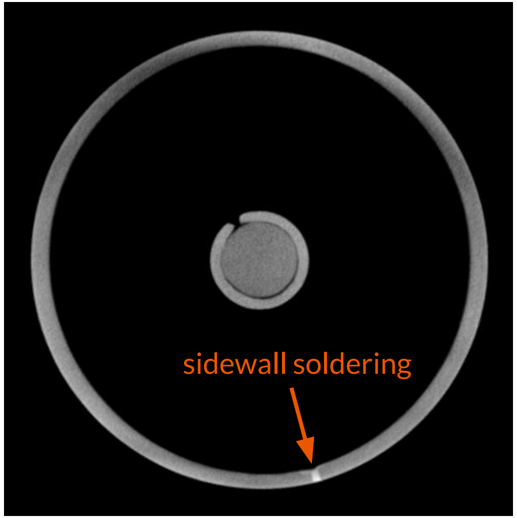


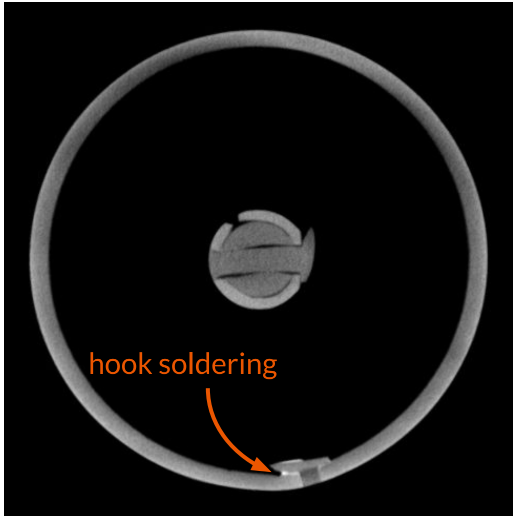
- The hooke wheron the springe hangeth in the barell is firste ryvited into the barrell wher it is sodered, and after also sodered when the bottum of the barrell is sodered, and then the barell is turned firste trylie ~~be~~ with a toole, then smoothe with a fyle, after with a pomiston weat, & then with a harde charcoale, [9]
- *The hook where the spring is fixed in the barrel is first* ***riveted into the barrel where it is soldered****, and after* ***also soldered*** *when the bottom of the barrel is soldered, and then the barrel is turned at first with a tool, then smoothed with a file, after with a pumice stone wet, & then with a hard charcoal*

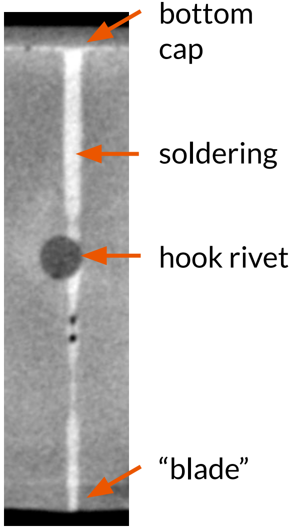
[9] [7] Evelyn papers, folio 9 verso

Manufacturing and assembly of the barrel

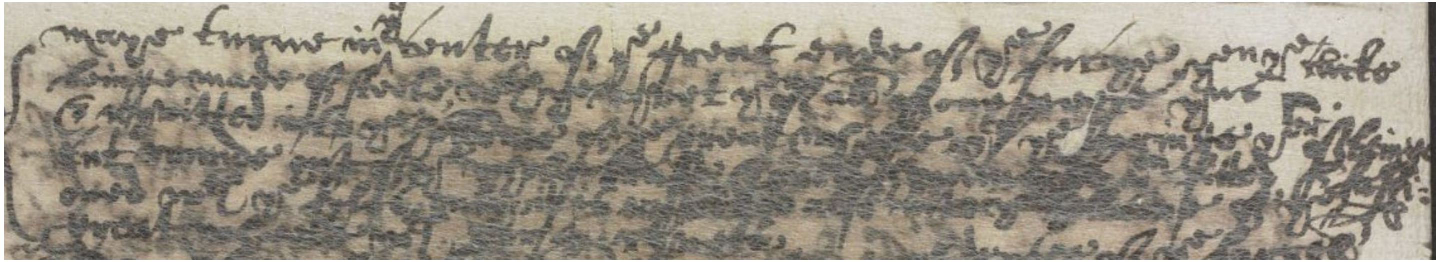
- The rivet of the hook is positioned **at the boundary of the barrel sidewall soldering**
- The hook is also **soldered** in the sidewall of the barrel
- Something interesting to notice: the 4 “blades” of the sidewall that keep in place the dovetailed barrel cap are **filed into the sidewall** (as seen on the soldering), probably for mechanical strength → other parts of the mechanism are also made from “rough” brass pieces (*e.g.* the support the the driving wheel), a common practice at that time (also the case of the pascalines lantern pinions)







Fusee wheel

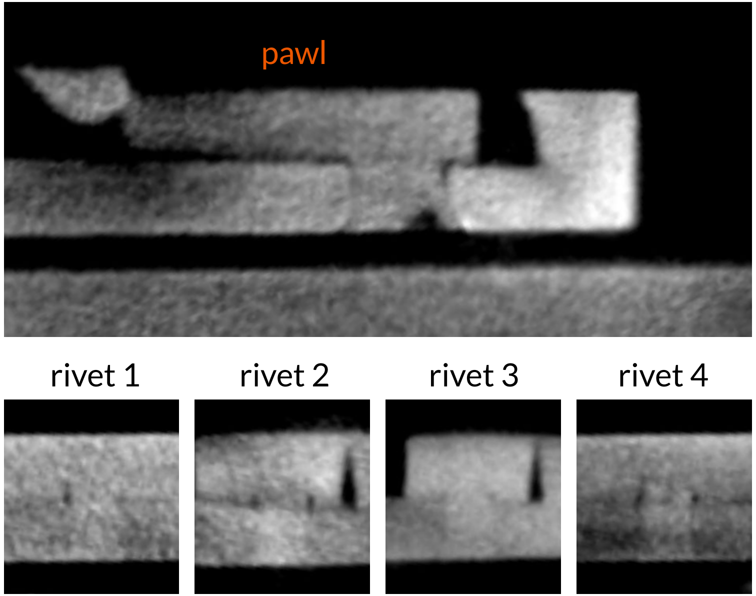


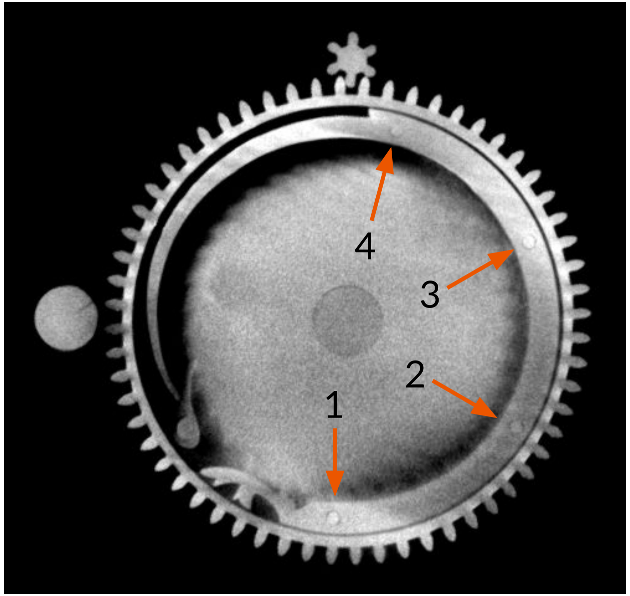
- maye turne in the center of the great ende of the fuccye then the clicke
being made of steel, with the ryvet therof all of one peece thus,
& ryvitted into the hollowe of the great wheele, then the springs therof beinge
cut round out of the whole brasse, & well hammered then fitted, & fashi-
oned with the fyles only, it is ryvetted also into the hollowe of the
great whele, with 3: or 4: ryvets, [10]
- *may turn in the center of the great end of the fusee, then* ***the pawl is made of steel, with the rivet all of one piece, & riveted into the hollow of the great wheel****, then the spring is being cut round out of the whole brass, & well hammered then fitted, & fashioned with files only,* ***it is riveted also into the hollow of the great wheel, with 3 or 4 rivets***

[10] [7] Evelyn papers, folio 11 verso

Fusee wheel

- The pawl if made of one piece with its rivet and riveted into the fusee wheel
- **The pawl spring is also riveted,** the rivets are covered by gilding but visible on cut views, they are located at the edges of the fusee arbor (see next slides)
- No solder is seen between the spring and the wheel





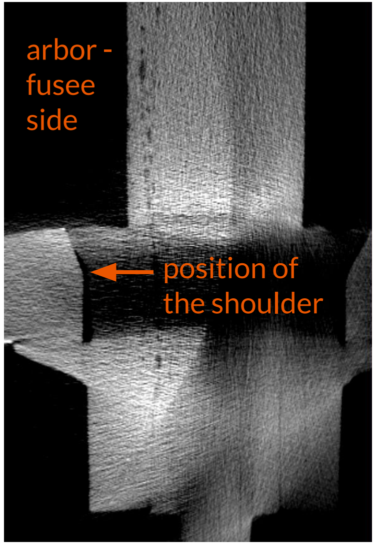
Fusee arbor

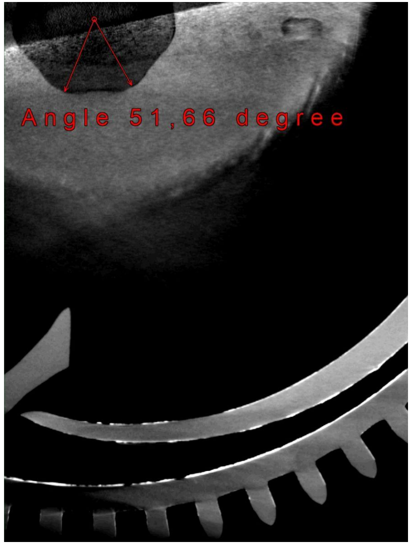
- The aber of the great whele is in lyke sort ryvitted therunto with a shoulder ~~of~~ least in the turninge ~~ther~~ of the aber without the solderinge of any brasse therunto, [11]
- *The arbor of the great wheel is in like sort* ***riveted thereunto with a shoulder left in the turning of the arbor without the soldering of any brass thereunto***

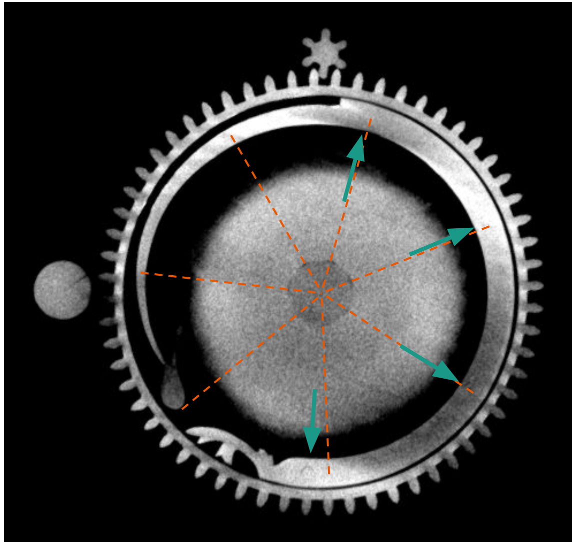
[11] [7] Evelyn papers, folio 10 recto

Fusee arbor

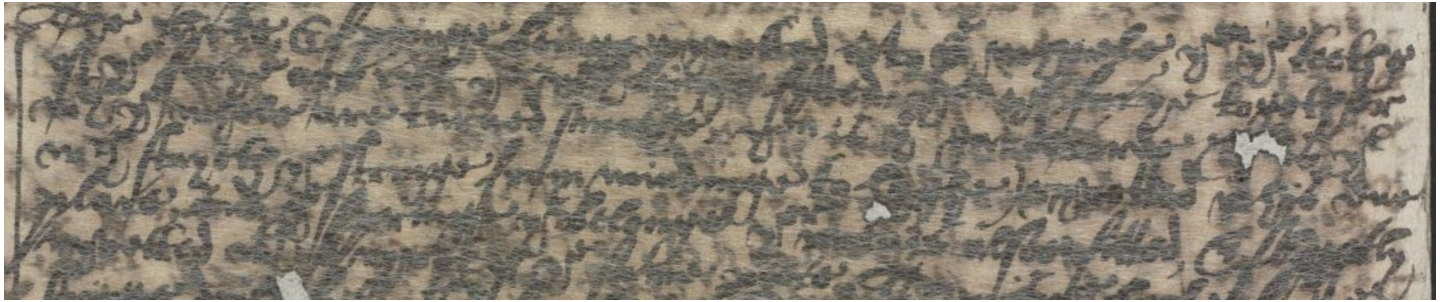
- The fusee arbor has an **heptagonal shoulder** which is located at mid-height in the fusee wheel
- The shoulder ends with a round shape which is the one visible from the outside
- The edges of the shoulder are pointing towards the 4 rivets of the pawl spring (pointed by the green arrows), that may have been used as markers
- No solder is seen between the arbor and the wheel







Garde-corde and fusee hook

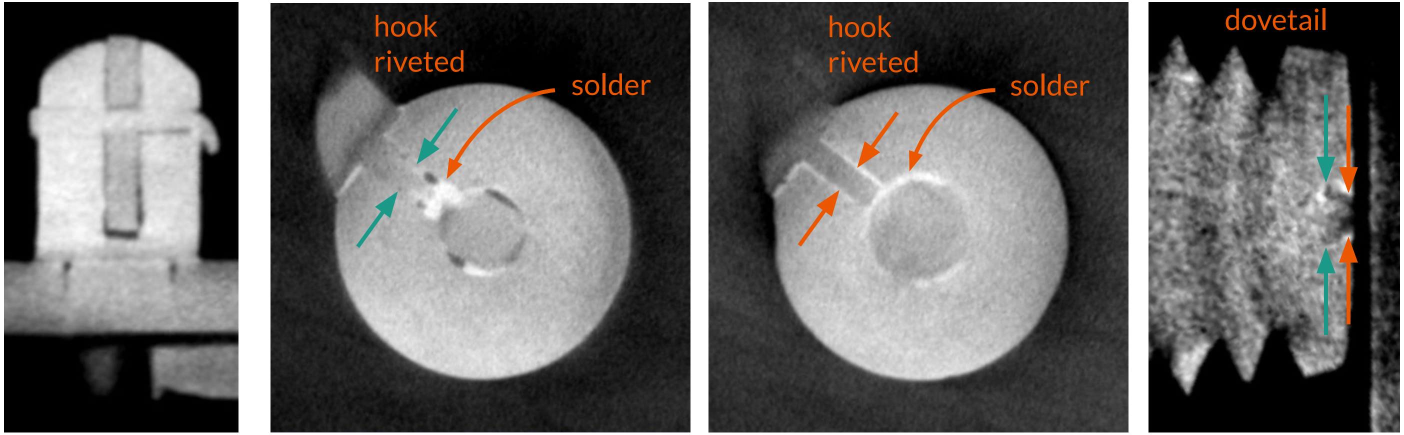


- The clicke and springe beinge ryvetted into the wheele, then the teethe of the fucye are cut the which beinge fytted, then the fucye together with the whele are turned smothe then is the gardecorde ([which] is that which stayeth the stringe from windinge to hyghe) ryvetted in his due place, And the springe that belongs therunto is alsoe fitted, & slyghtly ryvetted with a ryvet of the same peece, [12]
- *The pawl and the spring being riveted into the wheel, then the teeth of the fusee are cut and adjusted, then the fusee together with the wheel are turned smooth, then is the* ***garde-corde*** *(which prevents the spring from winding too high) riveted in his due place, and* ***the spring*** *that belongs thereunto is also fitted, & slightly* ***riveted with a rivet of the same piece***

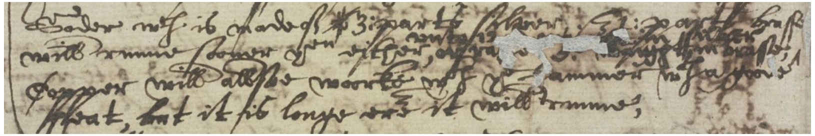
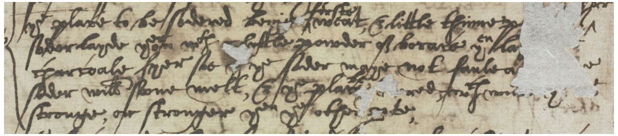
[12] [7] Evelyn papers, folio 11 verso

Garde-corde and fusee hook

- The base of the *garde-corde* is riveted in the back-plate (no solder)
- The spring of the *garde-corde* is made of one piece with its rivets which is riveted into the back-plate
- Something noticed on the cut views: the hook of the fusee, which is also riveted and soldered, is **dovetailed**, most probably to prevent it from rotating into its housing



Soldering of the fusee square arbor

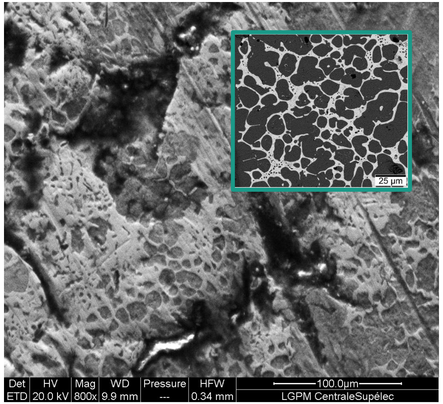
- Soder which is made of ~~2~~ 3 parts silver & 1 parts brass [...] [13]
- *The solder is made of ~~2~~ **3 parts silver & 1 part brass** [...]*
- the place to bo sodered beinge firste weat, & little thinne p[eeces] of soder layde theron with a lyttle powder of borace then lay { } charcoale fyer soe that the soder maye not faule a{ } soder will soone melt, & the place be sodered which wilbe the { } stronge, or stronger then the other p[ar]te, [14]
- *the place to be soldered being first wetted, & little thin pieces of solder laid thereon with a little powder of **borax** then laid { } charcoal fire so the the solder may not fall a{ } solder will soon melt, & the place soldered which will be the { } strong, or stronger than the other parts*

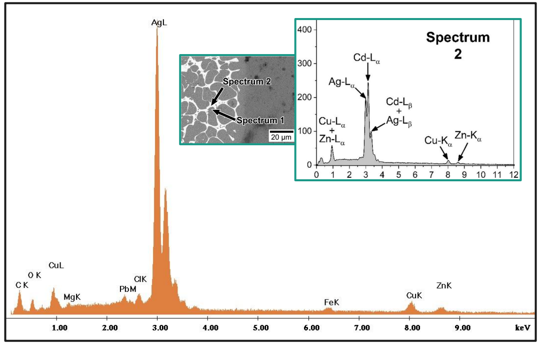
[13] [7] Evelyn papers, folio 8 verso (left picture)
[14] [7] Evelyn papers, folio 8 verso (right picture)

Projet Simon Le Noir

Soldering of the fusee square arbor

- Analysis of the solder with SEM: mostly made of **silver with brass in small quantity**
- Zoom on the area with solder: "stringy" structure consistent with recent analyses conducted on a silver-brass-cadmium solder of similar composition [15]
- **Borax seems to be detected** → consistent with the method described in the manuscript + we know that 17th-century French clockmakers used borax (*cf.* the inventory of the goods of Loys Vautier [16])





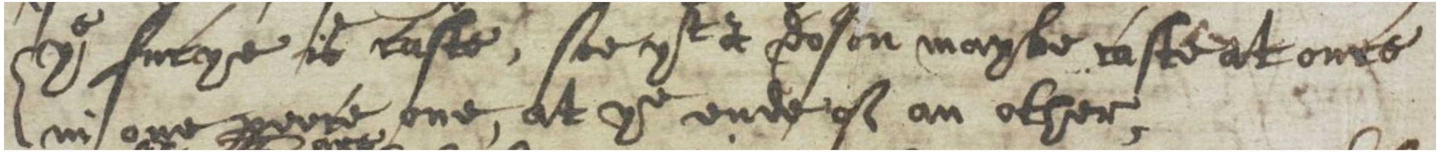
EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

Elem	Wt %	At %	K-Ratio	Z	A	F
B K	12.95	50.32	0.0513	1.1469	0.3456	1.0000
O K	4.93	12.94	0.0073	1.2051	0.1235	1.0002
NaK	1.43	2.62	0.0036	1.1262	0.2247	1.0013
AgL	70.47	27.44	0.6701	0.9353	1.0167	1.0000
CuK	6.15	4.07	0.0601	1.0173	0.9596	1.0000
ZnK	4.06	2.61	0.0402	1.0209	0.9692	1.0000
Total	100.00	100.00				

Element	Net Inte.	Backgrd	Inte. Error	P/B
B K	3.26	1.54	7.88	2.11
O K	10.22	2.29	3.83	4.46
NaK	7.16	5.59	6.09	1.28
AgL	378.23	11.08	0.54	34.13
CuK	18.83	5.74	2.98	3.28
ZnK	10.26	5.09	4.49	2.02

[15] [9] T. F. de Abreu Santos *et al.*, *Microstructural Evaluation of Copper Brazed Joints Using Silver-Based Filler Metal*, Metallography, Microstructure, and Analysis, 10, 2021, pp.174-183 (pictures from p.179)
[16] [10] E. Develle, *Les horlogers blésois au XVIe et au XVIIe siècle* (Rivière: Blois, 1917), p.52

Fusee manufacturing



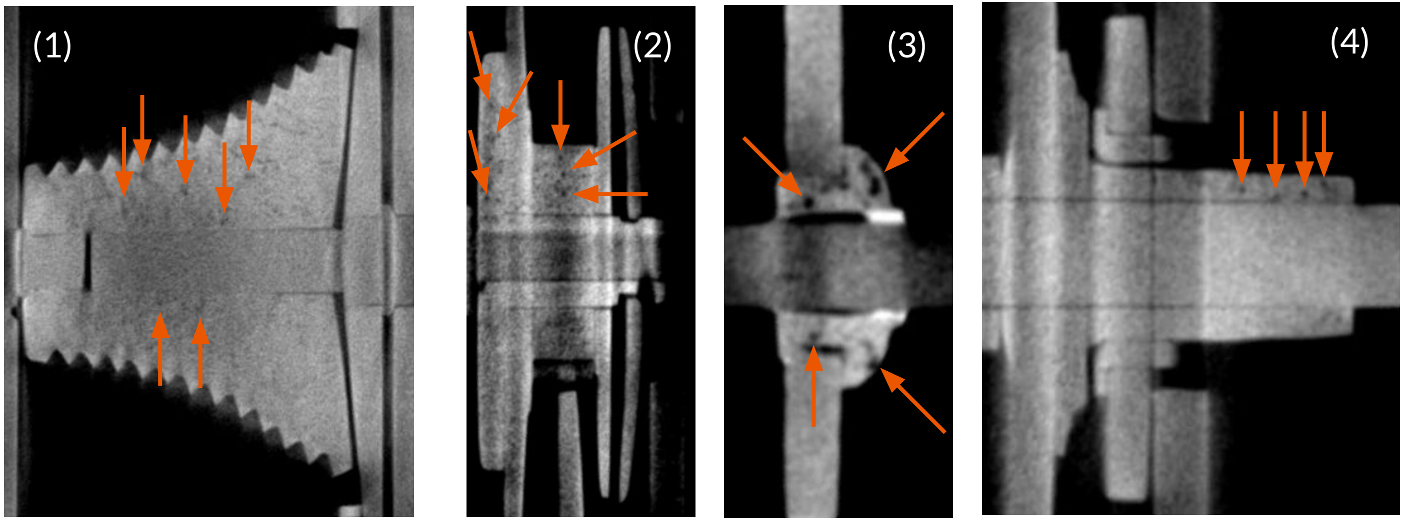
- fucye,
  the fucye is caste, soe that a dos[e]n maybe caste at once
  in one peece, one, at the ende {o}f an other, [17]
- *fusee,*
  the fusee is casted, so that a dozen may be casted at once in one piece, one, at the end of another

[17] [7] Evelyn papers, folio 8 verso

Introduction
Tomography
Bibliography
Analyses
Plates
Barrel
Fusee
Bushes
Rivets
Bores
Conclusion

Fusee manufacturing

- The fusee is **casted without any hammering**: some round-shaped air bubbles can be noticed on the cut views, *e.g.* view 1 at left
- Similar bubbles are noticed on **several other parts**: the pinion of the driving wheel and the piece that supports this wheel (view 2), the collet of the contrate wheel (view 3), the hour hand canon (view 4)…
- Spectroscopic analyses show that **all these parts were made by the same manufacturer** (same zinc concentration + same ratio of nickel & tin impurities)



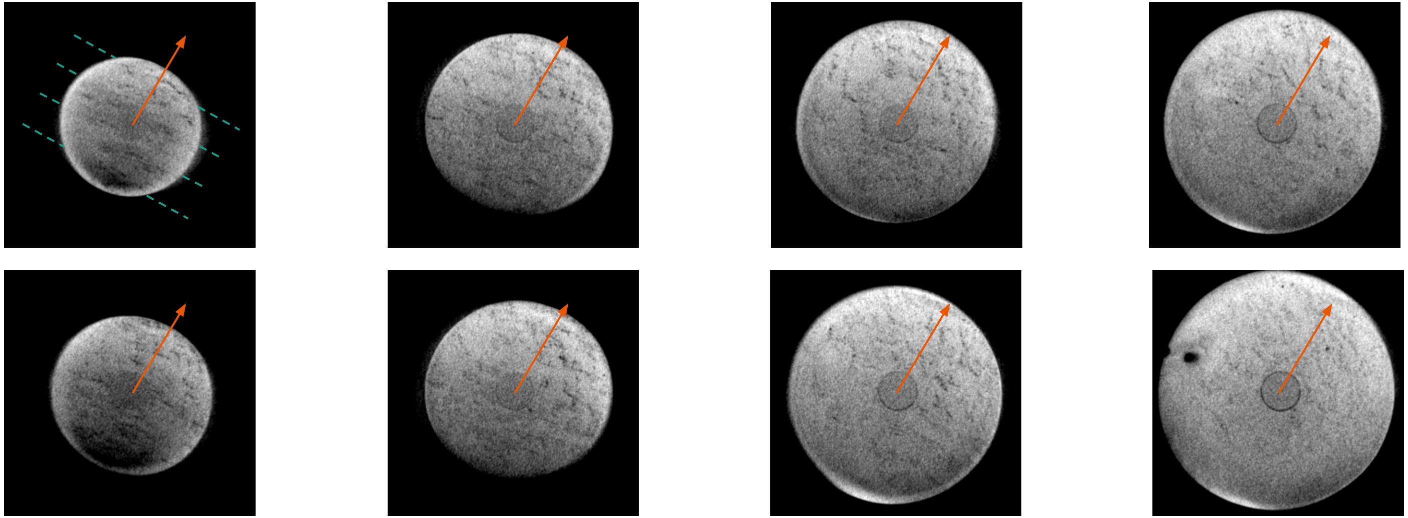
Projet Simon Le Noir

Fusee manufacturing

- The bubbles are globally dispersed inside the fusee though mainly grouped in a **preferential radial direction** where they are aggregated in **layers**

→ the pouring gate of the mould was possibly far from the ends of the fusee [18]

→ **horizontal** casting as suggested by the manuscript, with one fusee at the end of another?



[18] [11] M. Mödlinger, *Micro-X-ray computer tomography in archaeology: analyses of a Bronze Age sword*, Insight - Non-Destructive Testing and Condition Monitoring, January 2008, p.2

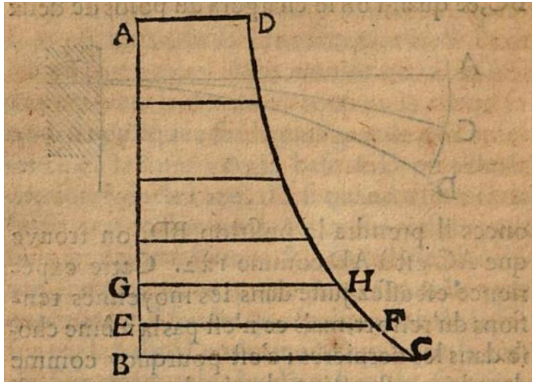
Shape of the fusee

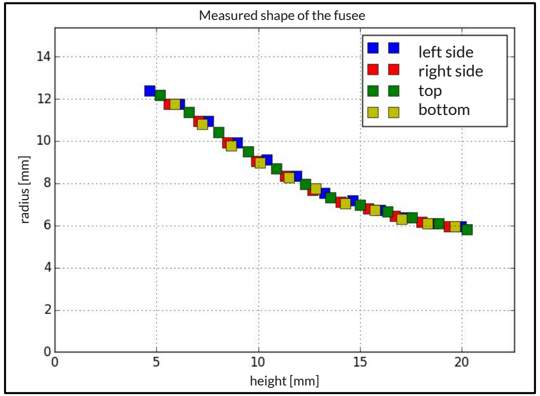
- The profile of the fusee was measured on 4 cut views at the top of the groove "triangles" (bottom right figure)
- Philippe De la Hire calculated the theoretical shape to keep the driving torque always constant: the fusee "*ne doit pas être tout-à-fait conique comme l'expérience l'a fait connoître ; mais elle doit être un peu creuse vers le milieu*" ("shall not be totally conical as experienced, but with a little hollow close to the middle" ; *cf.* top right figure) [19]
- <u>Hypotheses considered by De la Hire</u> :
- the force exerted by the spring is proportional to the number of winding turns of the barrel, which is an "*assez juste* [hypothesis] *dans les moyennes tensions du ressort*"
- the "*entortillement en spirale*" ("spiral kinking") is neglected → the string "*tourne en cercle*" ("turns in circles")
- the thread measured vertically is constant

→ one can demonstrate the theoretical formula of the profile:

$$\boxed{r(z) = \frac{A}{\sqrt{z + z_0}}}$$

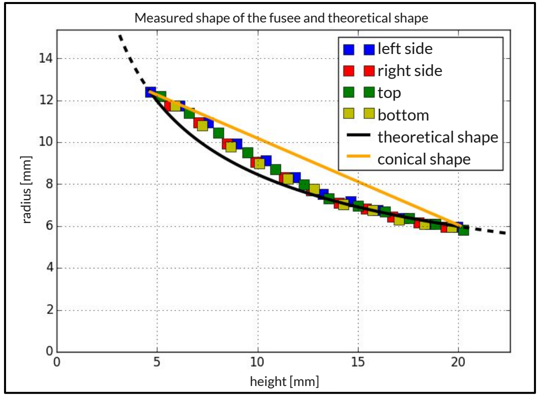
[19] [12] P. De la Hire, *Traité de mecanique [...]* (Paris: Imprimerie Royale, 1695), pp.231-237

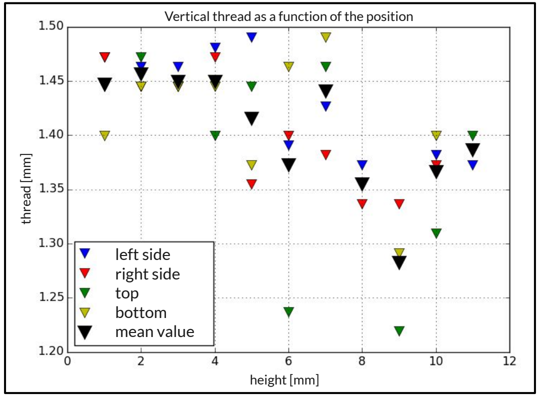




Shape of the fusee

- One can calculate the theoretical profile based on the 2 extreme diameters of the fusee
  → by superimposing this profile with the real profile, one can notice that they are quite consistent when the radius is low but a bit different at higher radius (see top right figure)
  → **the fusee has indeed a "hollow" close to the middle**, as suggested by De La Hire, and may have been cut from an initial conical shape (in orange on the graph)
- It has also to be noticed that there is an **inflexion point** on the profile (close to h=8mm on the graph) and that the vertical thread is **not constant** (see bottom right figure)
  → the fusee has been necessarily **cut manually without the use of a specific lathe**, probably through the method described in the manuscript
- The profile allows to calculate the number of turns :
  - of pre-winding of the barrel: **~4.3 tours**
  - of maximal winding: **~4.8 tours**
  → **consistent with the value of 4 turns classically met** [20]





[20] [8] Thompson, *"Summe Dyrections"*, p.183 & p.186

Bushes of the T-shaped bridge

- The internal diameter of the bush on the intermediate wheel bearing was accurately measured and is around **2.93mm** (*cf*. figures at right), and **the same diameter at about 0.01mm can be found on the pillars holes (both those of the back- & front-plate), and also on the minute wheel arbor (so the hole in the hour canon)**

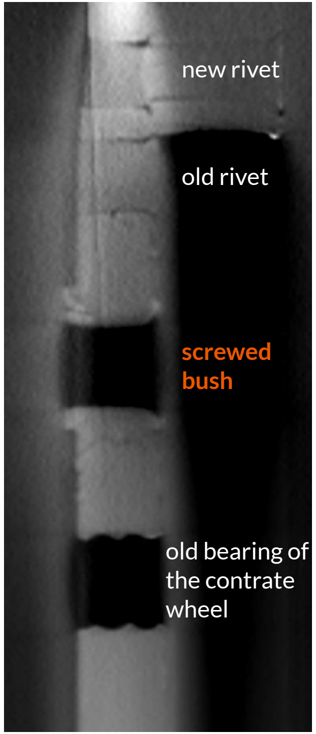
  → it is highly improbable that 2 clockmakers may have used a similar drill (less than 1/100^{e} mm of discrepancy)

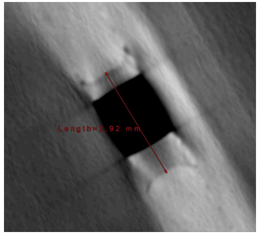
  → **this bush is probably from Le Noir himself**
- Another bush can be noticed on the bearing of the contrate wheel, screwed in the T-shaped bridge

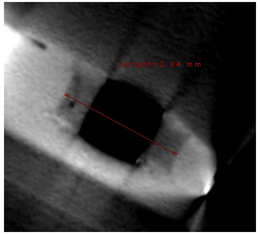
  → the thread of ~0.35mm is triangular, maybe metric?

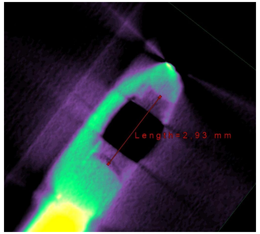
  → repair of rather poor quality carried out after gilding + screwed bushes were not used before the end of the 18th century [21]

  → **most probably a repair from the 19th century**









[21] [13] C. F. Vogel, *Practischer Unterricht von Taschenuhren* (Leipzig: verlegts Bernh. Christ. Breitkopf und Sohn, 1774), p.207

Internal diameters of the rivets

- Most of the parts are put together with rivets (very few screws / pins)
- It is possible to measure the internal diameter of the rivets (so the initial hole / drill diameters) with a great accuracy on cut views

  → this enables to compare the parts between them, given that the internal diameters **cannot be measured from the outside** so they could not have been reproduced on apocryphal parts
- The table at right shows the repartition of the measured diameters as well as some hole diameters for comparative purpose

  → **these diameters can be grouped in 5 "clusters" which are met from one part to another**

  → no metric value as expected

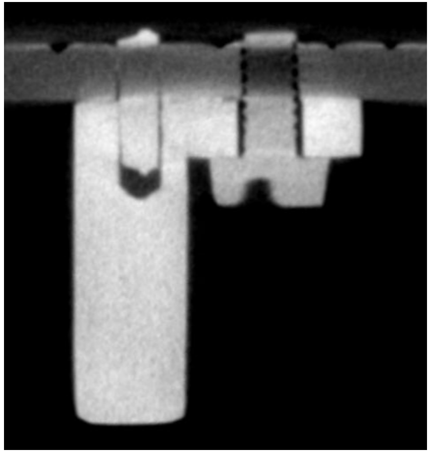
  → **this consolidates the overall authenticity of these parts**

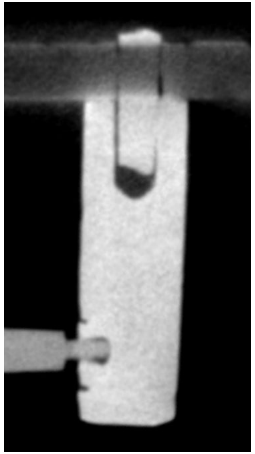
Part	Positions & number	Diameter (mm)
Front-plate	Rivets of the T-shaped bridge (3)	**1.06 +/- 0.01** (1) **1.39 +/- 0.04** (2)
	Unused hole (1)	**1.29 +/- 0.02**
Back-plate	Lower potence pin (1)	**1.42 +/- 0.01**
	Unused holes (2)	**0.88 +/- 0.01**
T-shaped bridge	Rivets (4)	**1.12 +/- 0.01** (1) **1.30 +/- 0.01** (3)
	Old bearing (1)	**1.42 +/- 0.01**
Verge cock	Pins (2)	**1.41 +/- 0.01**
Motion-work bridge	"Ear" pins (2)	**1.51 +/- 0.10**
Suspension cheeks	"Ear" pins (2)	**1.47 +/- 0.14**
	Pins to put the cheeks together (2)	**1.12 +/- 0.02** (1) **1.06 +/- 0.02** (1)
Minute wheel	Disc rivets (3)	**0.85 +/- 0.03**
Fusee wheel	Spring rivets (4)	**1.06 +/- 0.02**

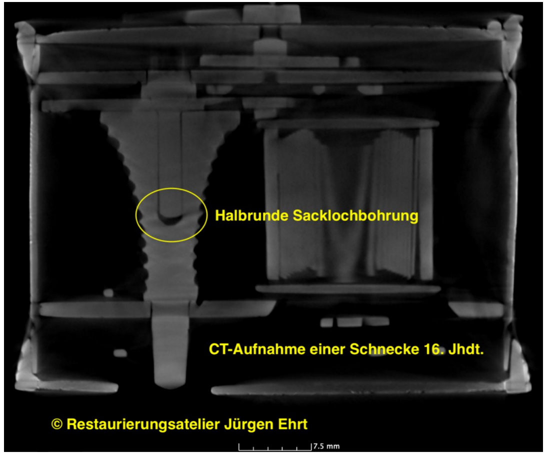
N.B. : the ~1.4mm & ~1.5mm diameters are very close to the fusee thread, around 1.45mm

Drilling of the bottom potence

- In the old time, drilling was carried out with “aspic tongue” drills
  → these drills were less hard than today's and had to be sharpened regularly
  → the bore in the lower potence of the crown wheel is slightly rounded and asymmetrical, and its angle does not correspond to any modern standard (around 100-110°)
  → similar to the hole of comparable diameter in the fusee of a 16^{th}-century “tambourin” watch [22] (bottom right figure)







[22] [14] J. Ehrt, *Untersuchung und Auswertung einer sich als „HorizontalTischuhr aus dem 16. Jahrhundert“, ausgebenden Uhr mit astronomischer Anzeige*, 2022, p.20

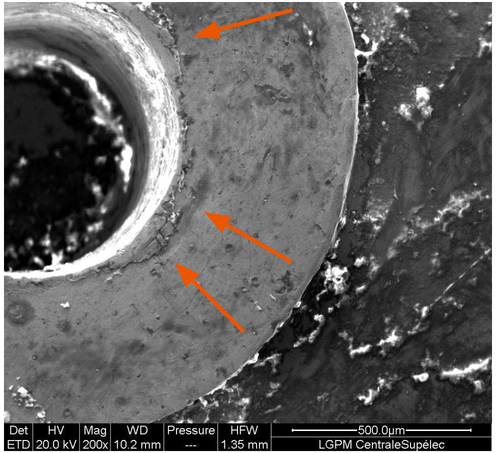
Drilling of the verge bearings

- the Cocke is that wherin the upper pyvet of the ballance
  Turneth, It is made of a thicke peece of brasse, hammered
  thinne at the ends, & bothe the upper notche, & under notche
  strooke on the side of an anvile in the hammeringe, The hoale in the middell
  beinge first drilde, then strooke, with a (squayre) Poonche, [...] [23]
- *the cock is where the upper pivot of the balance turns, it is made of a thick piece of brass, hammered thin at the ends, & both the upper notch, & under notch rubbed on the side of an anvil in the hammering, the hole in the middle being first drilled,* ***then rubbed, with a (square) punch,*** *[...]*

[23] [7] Evelyn papers, folio 11 recto

Drilling of the verge bearings

- On the verge bearings, the brass burrs caused by the drilling were **flattened** to get a smooth surface
  → this is <u>not</u> the consequence of the friction caused by the verge arbor because this arbor is not in direct contact with the surface of the bearing (its axial displacement is constrained by the bronze bushes of the bearings)
  → a punch was probably used to “rub” the surface as suggested by the manuscript, similar traces are observed on the punched holes of the “Geneva sphere” (figures at the bottom center / right [24])

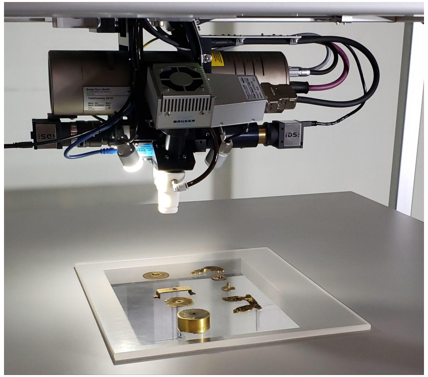


[24] [15] M. Martinón-Torres, *Metallurgical analysis of the Geneva sphere*, 2017

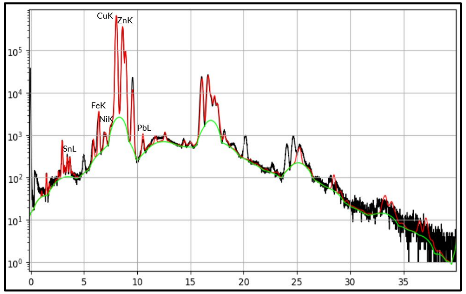
Projet Simon Le Noir

Conclusion and perspectives

- The manufacturing techniques observed on the mechanism are in very good agreement with those described in Evelyn's manuscript and other documents from this era
- This confirms the authenticity of some parts of the mechanism that were "suspicious" (the bushes…), some repairs have also been identified
- This study enabled to get new insights on mid-17th century clockmaking techniques
- **These are the first scans of an historical clocks that are available in open-source**
- Follow-up: XRF analyses are being performed to identify the trace elements in brass parts, to be compared with the brasses of other 17th-century clocks (Thuret / Coster / …)



XRF analyses at the CRC



Spectre XRF du couvercle du tambour

I would like to thank Benjamin Smaniotto (LMPS), Dr. Tobias Gabriel (Zeiss) et Prof. Dr. Patrick Rocca (Arithmeum) for making this study possible.

Bibliography

References by order of citation:

1. A. Gomand, *Simon Le Noir et l'application du pendule aux horloges : une histoire parallèle ?*, Horlogerie Ancienne, 91, June 2022, online: https://agomand.github.io/asln/en/documents.html
2. A. Gomand, *Compléments dans l'affaire Simon Le Noir*, Horlogerie Ancienne, 93, June 2023, online: https://agomand.github.io/asln/en/documents.html
3. A. Ramsey, *X-ray Tomography of the Antikythera Mechanism* (Kerastari, 13 June 2012), online: https://www.atnf.csiro.au/people/atzioumi/Antikythera2012/presentations/X-ray_Tomography-Ramsey.pdf
4. T. Freeth *et al.*, *A Model of the Cosmos in the ancient Greek Antikythera Mechanism*, Nature Scientific Reports, 11, March 2021, online: https://www.nature.com/articles/s41598-021-84310-w
5. J. Ehrt, *Ein Mythos auf dem Prüfstand - Die Untersuchungen an der sogenannten Peter Henlein-Uhr des Germanischen Nationalmuseum Nürnberg* (Restaurierungsatelier Jürgen Ehrt, 2021), online: https://www.uhrenrestaurator.de/de/ein-mythos-auf-dem-pruefstand

Bibliography

6. https://www.renaissanceuhr.de/uhren/renaissanceuhren/burgunderuhr/
7. British Library : Add. MS 78425 – Evelyn Papers. Vol. CCLVIII, fol. 8 recto - 14 recto, online: https://access.bl.uk/item/viewer/ark:/81055/vdc_100110232103.0x000001
8. D. Thompson, *'Summe Dyrections towards the makinge of a smale watch, of brasse' – A guide to watchmaking techniques in the seventeenth century*, Antiquarian Horology, 44-2, June 2023
9. T. F. de Abreu Santos *et al.*, *Microstructural Evaluation of Copper Brazed Joints Using Silver‐Based Filler Metal*, Metallography, Microstructure, and Analysis, 10, 2021, online: https://link.springer.com/article/10.1007/s13632-021-00722-0
10. E. Develle, *Les horlogers blésois au XVIe et au XVIIe siècle* (Rivière: Blois, 1917)
11. M. Mödlinger, *Micro-X-ray computer tomography in archaeology: analyses of a Bronze Age sword*, Insight - Non-Destructive Testing and Condition Monitoring, January 2008, online
12. P. De la Hire, *Traité de mecanique [...]* (Paris: Imprimerie Royale, 1695), online: https://www.google.fr/books/edition/Trait%C3%A9_de_mecanique_ou_l_on_explique_to/jRKUyJN7vA4C?hl=fr&gbpv=0

Bibliography

13. C. F. Vogel, *Practischer Unterricht von Taschenuhren* (Leipzig: verlegts Bernh. Christ. Breitkopf und Sohn, 1774), online: https://www.digitale-sammlungen.de/de/view/bsb10305943

14. J. Ehrt, *Untersuchung und Auswertung einer sich als „HorizontalTischuhr aus dem 16. Jahrhundert", ausgebenden Uhr mit astronomischer Anzeige*, 2022, online: https://www.uhrenrestaurator.de/de/pdf-download-ein-mythos-auf-dem-pruefstand?task=weblink.go&id=6

15. M. Martinón-Torres, *Metallurgical analysis of the Geneva sphere*, 2017

The figures that are not associated to any reference are from the author.