Passemant's moving sphere clock in Versailles A plea for better restorations and documentations*

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The survival of a clock relies on its documentation,
and on the openness of this documentation,
not on the making of secret documents that no one can see.

Contents

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1 Introduction

Claude-Siméon Passemant (1702-1769)[1] was scientific instrument maker to King Louis XV of France. Among other things, he constructed or designed microscopes, telescopes and two elaborate astronomical clocks.

One of these clocks is a so-called "moving sphere clock" now exhibited in the castle of Versailles (Inv. VMB 1037, figure 1). It seems that this clock was conceived around 1729, approved by the Royal Academy of Sciences in 1749 [1, p. 183], completed in 1750, shown to the King Louis XV at the castle of Choisy in 1753 [17, 12] and installed in Versailles in 1754 [24, 45, 46]. The clock is more than 2 metres tall and crowned with a celestial sphere. Contrary to what one might think, the sphere is actually not moving, but it contains moving elements. The clock also shows the date, time, and phases of the moon. The year is displayed as a system of four independent digits. The bronze case was made by Jacques Caffieri (1678-1755) and his son Philippe (1714-1774).

2 Mysteries and legends

Passemant's clock has been surrounded by a veil of mystery, legends and of course the reputation of being a very complex clock. The duc de Luynes, who described the installation of the clock in Versailles [29, 30] called it a

[1]For biographical notices on Passemant, see in particular Fontenai [25, p. 266-268], Sue [96], Beuchot [10], Daumas [21] and [22, p. 347-350], Maurice [68], King [57], Augarde [4] and Beaudouin, Brenni & Turner's *Dictionary* [6]. I have moreover given an extensive list of references on the clock, as well as on the bronzes, which are not always cited in the text.

Figure 1: Passemant's astronomical clock at the castle of Versailles (Photograph: Trizek, Wikimedia, 2011, and engraving from Dumas [40]).

"miracle of science" [29, p. 90]. This installation founded the room known as "Salon de la pendule" [31, 33, 32].

Passemant's clock remained in Versailles until 1797. It was then sent to the *Conservatoire des arts et métiers* and chosen to be displayed at the Tuileries palace. But it was first put in the care of Antide Janvier [28, p. 48], and it stayed in his hands or in those of B.-H. Wagner, until 1828 when it was returned to the *Garde-Meuble*, the administration in charge of the furniture in the Royal palaces [5, p. 32, 63-65].[2] The clock was returned to Versailles in 1833 [82, p. 168]. During WWII it was put in storage in the castle of Chambord, with many other artworks [62, p. 22] and was thus spared from being looted by the German troops. The pendulum was very likely initially encased, as it appears from a sketch by the Caffieris [8, p. 195-196], [100, p. 55].[3] This case was probably lost in the first half of the 19th century and a new pendulum was added.

It is certain that the reputation of the clock quickly spread and even crossed borders, and we can find mention of its installation in Versailles in Germany shortly afterwards [76, 103]. The clock was described in Le Roy's *Étrennes chronométriques* in 1758 and 1760 [63, 64] and in 1765, it was listed as one of the "monuments erected to the glory of Louis XV" [80, p. 31], when the King was still reigning. Diderot and d'Alembert's *Encyclopédie* [41, p. 305] writes that Passemant's clock is the most perfect "moving sphere" clock of which they are aware, but then the *Encyclopédie méthodique*, largely based on the *Encyclopédie*, wrote in 1789, about spheres such as that of Passemant, that "these very complex machines are of no use" [42, p. 66], although this does not seem to have been copied from the *Encyclopédie*'s corresponding article on spheres.

In 1849, Dubois wrote that Passemant's clock is the most important of the clocks made under the reign of Louis XV [38, p. 178]. Such superlatives have continued to this day.

Incorrect informations are supplemented once in a while, and the new "facts" then get a life on their own. For instance, in 2013 the popular

[2]Demerson wrote in 1829 that the clock was in the hands of Janvier at the "Hôtel des Menus Plaisirs", rue du Faubourg Poissonnière in Paris [36]. The "Menus Plaisirs" were a storage place for the court, but it was also where Janvier was lodging.

[3]There are also supposedly four drawings of the clock at the *Musée des arts et métiers* in Paris (Inv. 13571.480/1 to 4, cited by Delalex [34]), but I haven't seen them. One of them was reproduced by Pinault-Sørensen [86]. The National Archives also have a file on the clock (013510 1er dr. feuillet 23, cited by Mongruel [74, p. 86]) which I haven't seen either.

French historian Franck Ferrand wrote that Passemant's clock gave the official time to the entire French Kingdom from 1750 until 1792 [43]. But the author seems to ignore that every city had its own time, and that there was no way to synchronize clocks. Consequently, having the same time in an entire kingdom was meaningless. Passemant's clock may have been the time reference in Versailles, but certainly not beyond that.

There have also been a few timid echos of "bad taste," the clock actually suggesting a human body without arms [2, p. 184]. In an article published in 1999 on the clock and the Y2K problem, Belleret also noted its anthropomorphic shape [7]. Kjellberg wrote that it reminded of some futuristic robot [58, p. 162]. And Julia Kristeva, in her novel "The enchanted clock", even went so far as writing that Passemant had presented "his priapic clock to Louis XV" [61].

There have only been a few interventions on Passemant's clock. The most notable one was the one by Antide Janvier who put the clock back in working order at the beginning of the 19th century, and who also gave a number of details on the astronomical gears. However no plans seem to have been made public, neither of the astronomical part, nor of the simpler parts such as the going work, the striking works or the parts making up the calendar, although Janvier game some hints on the mechanisms.

This clock has thus never been seriously documented. It is as if scientific research on the clock has been nonexistent for the past 200 years, and one wonders what curators and clockworkers[4] have done, except for allowing copies to be made in the second half of the 19th century. The only exception seems to be the work of Maurice, who added some material to what Berthoud and Janvier had published.

The scarcity of documentation also applies to Passemant's astronomical clock in the Louvre museum, although it was recently restored and even lent to the Louvre Abu Dhabi. Surprisingly, we seem to live in a time where people confuse restoration with documentation, and believe that a clock restored in a great museum cannot be imperfectly documented. But this is false and curators need to become aware of it and change it. We need to get rid of restorers who only clean and repair clocks. This is simply not enough. We also need to get over the culture of secrecy surrounding clocks. This time should long be bygone.

[4]I am using "clockworker" instead of "clockmaker," because most of the craftsmen who work on clocks do not make clocks anymore.

In fact, for the past 200 years we have been told that Passemant's clock is extremely complex. It has been shown at exhibitions, in particular the one held on sciences in Versailles in 2010-2011 [92] and it will again be prominently featured in the upcoming exhibition on Louis XV. In the past, curators and historians talked lavishly about the clock, mesmerized by the Caffieri bronzes [47, 67], but always repeating what others had written before them, as if the mechanisms did not interest them, or if they were convinced that they could not be understood. The clock has also been a backdrop and never really was at the forefront of the talk. And this clock seems to have become, at least for some people, a really mythical work.

Nowadays, Passemant's clock also epitomizes the tension in the curatorial world between on the one hand the desire to let the works be more accessible, and on the other hand the fear of seeing them copied. The truth, of course, is that you cannot have at the same time full accessibility and prevent copies. If works are to be made accessible to all, one also has to accept that these works are copied. This is what happened with other famous clocks, such as Harrison's chronometers in Greenwich. Of course, Passemant's clock has been copied, but in most cases the mechanisms have only been approximated, perhaps because when replicas were made the clock could not be dismantled.

The dilemma faced by curators has sometimes incompletely been solved by providing the public with more information, but not all information. For instance, some images can be shown, perhaps even animations, but not technical data, or dimensions. The buzz word in France is "mediation," which is the art of communicating things to the public, that is the art of digesting the complex stuff and only giving away the essential material and making it palatable. This trend, often carried by the "miracle" of 3D imaging, is however superimposed with the ideas that the public would not be able to understand all the details of a mechanism or even that technology in not "artistic" enough. Of course, very often, it is the curators themselves who lack the background in mathematics, mechanics and astronomy, and who believe that a complex mechanism has to be made interesting with colorful animations, and, above all, has to be simplified in order to become understandable.

I tend to disagree with these views, and I believe that complex mechanisms can be explained to most people, without oversimplifying them, but I also believe that the 3D technology is not the miracle solution.[5] It is not by adding a touch of 3D to a description that everything will become clear. However, 3D technologies can sure provide an interesting entertainement and, if used well, they can help improve understanding. They will however not cancel the need to think, reason and compute. A 10 minutes animation will not replace all the thinking, calculations and theoretical material that one needs to master in order to understand a complex mechanism. Look at it that way: an inventor has spent time designing and constructing an object, and understanding that object is also about understanding what the inventor did, and how he did.

Coming back to Passemant's clock, I believe that the complexity of this clock has been exaggerated. I am not claiming that the clock is not complex, but it is not *that* complex. It may seem complex, and the fact that few have really been looking at it may add to this veil of complexity. But it is only a veil.

In order to show that the working of the clock can be understood, I am going to explain how the moving sphere works. After that, I will give some details on the other parts of the clock and on the needs for a real scientific intervention on the clock.

3 The moving sphere

3.1 How the moving sphere works

The clockmaker, watchmaker, and historian Ferdinand Berthoud (1727-1807) published most of the gear ratios of the moving sphere, communicated to him by Janvier.[6] Berthoud does not give any plan of the gears, but it is not too difficult to produce the layout of figure 4. This drawing is of course hypothetical. Most of the teeth counts are probably correct, but the layout of the gears is approximate. Some of the wheels are actually

[5] For what it is worth, I would like to mention that I am the author of a 3D model of the Paris Notre-Dame cathedral clock, and that this model is freely available online, together with animations on *youtube* and an Android application ("Paris Notre Dame Clock").

[6] See Berthoud [9, v. 2, p. 197-204]. Additions are found in Janvier [55, 56] (with typos) and in Dubois [38] (also with typos). There are also some elements in Le Roy's *Étrennes* [64], but they were carried over by Dubois. Pearson [83] also gives a description of the clock and of its astronomical gears.

positioned differently than how I positioned them.[7] However, I believe that my figure represents a possible construction and it could actually be used by someone who would like to reconstruct Passemant's sphere. This alone makes it rather pointless to try to conceal the internal workings of Passemant's clock.

Figure 2: The clock with the moving sphere. (Photograph: Bob Holmstrom, with permission)

Let me now quickly review how the sphere works. The sphere represents the motion of the planets from Mercury to Saturn, as well as the Moon, within a glass sphere. There is a set of eight tubes with a vertical

[7]In fact, there doesn't seem to be an arbor with the pinions and wheels 7, 9, 53, 43 and 53, and instead pinion 7 meshes with wheel 103 (Saturn), pinion 9 meshes with wheel 98 (Jupiter), etc. This, however, doesn't alter the analysis of the works.

Figure 3: Detail of the moving sphere. (Photograph: Bob Holmstrom, with permission)

axis, six of which are carrying planets. These planets move in a horizontal plane which is the plane of the ecliptic.

We know that there is a drum or a barrel and that it makes one turn in five days. It is shown at the bottom of the drawing. This motion is sped up to a rotation of one turn in 48 hours. This is what Berthoud calls the "motrice." It is the base motion from which all the others are derived. This motion is transmitted (dashed line) to one of the tubes of the vertical assembly.

From this motion of one turn in 48 hours, one obtains the tropical month motion (27 days 7 hours), and from the latter the revolution of Mercury. In addition, one obtains the Earth's revolution in one tropical year.

The revolution of the Earth is then used to obtain the revolutions of Venus, Mars, Jupiter and Saturn.

The press release [18] for the restoration of Passemant's clock recalls that it took 36 years to build the clock. 36 years? It is said that Passemant spent 20 years to compute these gears, but these were not 20 years doing only this! If this time span is authentic, we can imagine that Passemant spent once in a while some time working on these gears. Some authors, such as Dubois in 1849, tried to explain that Passemant's work was very

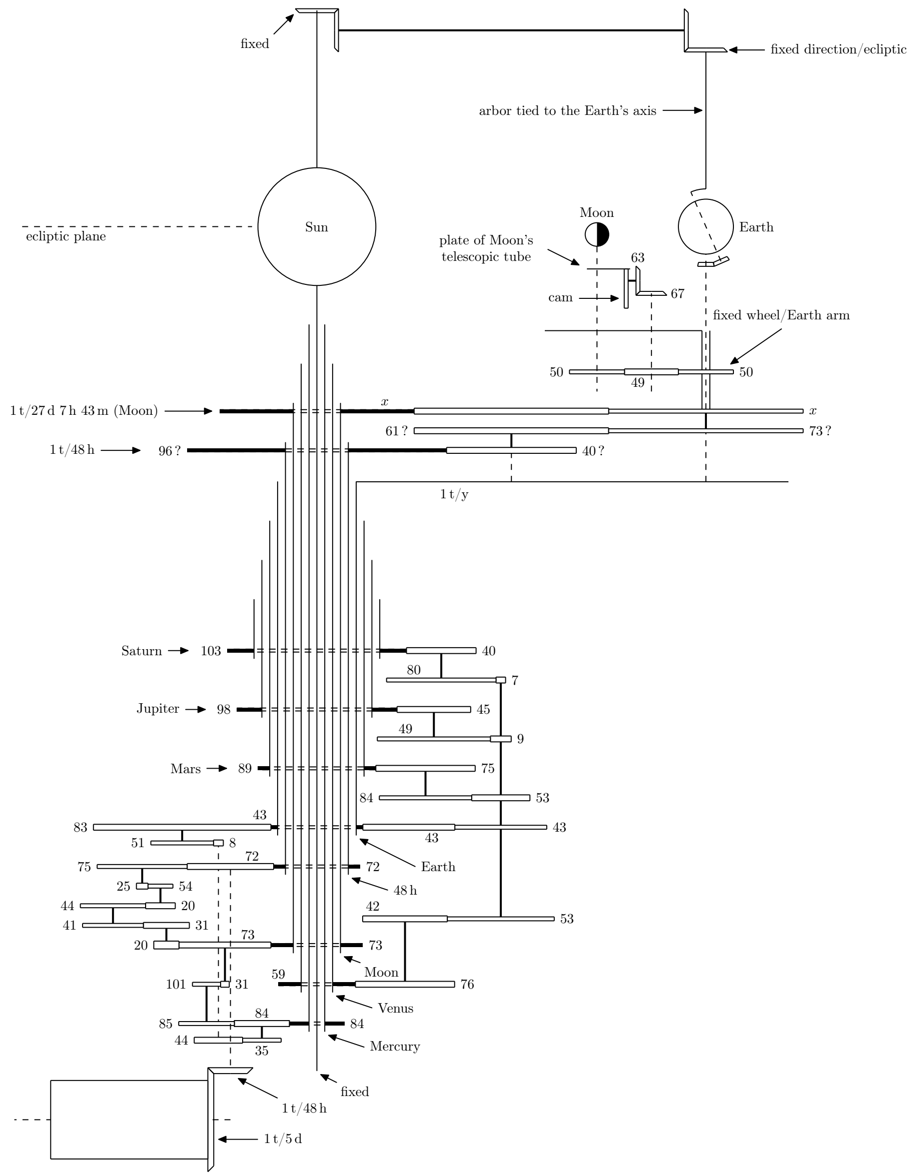

Figure 4: Principle of Passemant's moving sphere, hypothetical reconstitution based on Berthoud's data and various photographs and videos (youtube: `L9DSiAILKsI`, `wIqeG_sbYkA`, `WENtdEoVCbk`, facebook: `2014954678546955`). In fact, the layout is here a bit simplified, as there is no arbor with the pinions and wheels 7, 9, 53, 43 and 53, but it is nevertheless a possible construction and this does not alter the analysis of this document.

difficult because there were no extensive tables of primes at his time. This is true,[8] but the reality is that Passemant didn't really need a large table of primes, rather tables of divisors, which are not exactly the same. If Passemant did manipulate large numbers, he had to make sure that these numbers only contain factors no larger than about 100. If I am not wrong, there are no gears in the clock with teeth counts greater than 103.

It is also said that the clockmaker Louis Dauthiau spent twelve years constructing the clock on Passemant's design. But again, if this is true, it was certainly not because the clock was complex, but because he did not work only on that clock, or perhaps that he was not very efficient. In fact, it seems that these ten years overlap the 20 years of Passemant, so that the truth is probably not as simple as it is usually described. There are moreover no reasons to spend ten years constructing such a mechanism once the base data are at hand. I cannot stress enough that the curators should begin to have a real scientific approach and stop to constantly repeat the same things that were told in the past. Instead of telling us that the clock is complex, it would be much better for them to explain us the clock. It would also be much more useful for the scientific development of these works.

Adding work years by different individuals only gives a distorted view of the reality. With the same reasoning, we should say that it took 400 years (at the very least) to construct the Eiffel tower, because at least 200 workers have been working on site for more than two years, not counting all those working in the foundries. We need to stop saying such garbage!

That being said, with the teeth counts given in figure 4, one finds that the exact values used by Passemant are the following ones:

[8] I refer the reader to my census of mathematical and astronomical tables on `https://locomat.loria.fr` for a more accurate picture of what was available in Passemant's time.

tropical month	$\frac{224037}{8200}$	27.321585...	27d 7h 43m 4.97...s
Mercury	$\frac{15328467}{174250}$	87.968246...	87d 23h 14m 16.52...s
Venus	$\frac{3849943757121}{17134105000}$	224.694768...	224d 16h 40m 28.00...s
Earth	$\frac{3107299239}{8507500}$	365.242343...	365d 5h 48m 58.49...s
Mars	$\frac{1935847425897}{2818109375}$	686.931260...	686d 22h 21m 0.92...s
Jupiter	$\frac{92106487319}{21268750}$	4330.601813...	4330d 14h 26m 36.67...s
Saturn	$\frac{320051821617}{29776250}$	10748.560400...	10748d 13h 26m 58.57...s

The revolutions are expressed in days. The ratios do not have anything special, they have merely been obtained from the teeth counts of the wheels. Any clockworker can check these values. I want to stress that it is not because the integers given here are large that Passemant did manipulate these ratios directly. It is perfectly possible to work indirectly with large numbers.

Moreover, the accuracy of these values is of little importance. Whether an astronomical clock is accurate or not (compared to the actual heavenly motions) is not important, because all the astronomical clocks end up stopping, by lack of care. This is true for the large astronomical clocks such as those of Strasbourg, Besançon, Beauvais, Lyon, etc., and it is true for the small ones. But what is much more interesting is first to determine the values aimed by the author of the gears, and to find out how he selected approximations to these values. These approximations are sometimes the result of compromises or choices that we can only guess.[9]

[9] I will come back to the design of the astronomical gears in a moment, but I want to point out that Passemant's gear ratios had already been criticized more than 200 years ago by Janvier. In his *Manuel chronométrique* [56, p. 229], Janvier wrote that if Passemant had been on the right track, he could have computed his gears in two days, and that Alexandre had produced much better gear ratios already in 1734 [3, p. 181]. Such an objection was again voiced by Montucla in his posthumous *Histoire des mathématiques* [75, p. 797]. In 1857, Redier [87, p. 310] observed that Janvier's comments on Passemant were "the measure of the ignorance of an artist who had had a high reputation." In 1859, Redier [88, p. 286] reiterated his criticism of Passemant's mathematical skills and objected of Dubois calling him a "great mathematician." However, I think that Janvier's statements, repeated by Redier, are also prone of being misunderstood. It is indeed easy to find some gear ratios, but Passemant did not only have to find ratios, he also had to

Figure 5: Detail of the moving sphere gears from the right (left) and the back (right). (Photographs: Bob Holmstrom, with permission)

On the other hand, it is also interesting to see how the gears have been put in place, how the sizes of the wheels were chosen, what adaptations were made, etc. All this is much more interesting and more important than to discuss the pointless accuracy of such a clock. The accuracy, and perhaps this is not sufficiently understood, is not only the result of the machine, but also the result of the person who does take care of it.

In any case, this assembly of gears produced the motion of the planets as well as the motion of the tropical month, viz. the motion of the Moon with respect to the (moving) zodiac. On the figure, one can see that there is also a fixed central axis which carries the sun, as well as a fixed wheel set in the upper part. The Moon tube is set between those of Venus and the Earth.

The entire Earth-Moon system is carried by an arm fixed to the annual tube and makes therefore one turn in one year. This arm carries the Earth, whose axis is tilted by $23.5°$. That axis is maintained in the same direction of the ecliptic as a consequence of the gear located above it. Two pairs of bevel gears (or rather approximations thereof) make it possible to obtain this effect without any difficulty.

The Earth also has the rotation motion around its axis, but it rotates in one sidereal day with respect to the ecliptic. This internal motion is obtained from the base motion of 48 hours, by the gears I have given, or possibly by a variation of these gears. The ratio $\frac{96}{40}\times\frac{61}{73}\times\frac{1}{2} = 366/365$ makes it possible for the small wheel located under the Earth to make one turn in 23 h 56 mn 4 s, with respect to the ecliptic, and this motion is transmitted to the Earth's rotation axis.

Moreover, the tropical month tube makes it possible to obtain the correct orientation of the Moon with respect to the ecliptic, and hence also with respect to the line joining the Earth to the sun. Finally, there is probably on the Earth's arm a 50 teeth wheel, fixed with respect to the arm, and the lunar arm's rotation around the Earth also causes a 49 teeth wheel to rotate around this 50 teeth wheel. This causes on the one hand the rotation of the Moon on its axis in order to show the phase (the Moon does not have any surface details and the lit/unlit parts are permanent), and on the

imagine a layout and kinematic chains, which is a different matter. In fact, some of these things may have been done by Dauthiau, and it is in fact not always clear who did what. Mongruel, for instance, wrote that Passemant didn't "work with his hands" [74, p. 87]. Did Passemant only imagine the layout of the gears, or did he also find the gear ratios? We cannot really answer this question.

Figure 6: A detail of the moving sphere. One can see that the Moon is not correctly oriented, its unlit blue side not being opposite the sun. (excerpt of the press package for the 2010-2011 exhibition.)

other hand, with the help of two bevel gears of 67 and 63 teeth, it causes the rotation of a cam which moves the Moon vertically, the Moon being set on a telescopic tube. This cam is fixed to a dial which presumably indicates the latitude of the Moon. One consequently obtains on the one hand the synodic month, and on the other hand the draconic month. These two values are the following on the clock:

synodic	$\frac{96326276409}{3261914900}$	29.530591...	29d 12h 44m 3.10...s
draconic	$\frac{297359215274583}{10927414915000}$	27.212219...	27d 5h 5m 35.78...s

The age of the Moon can be read on a fixed engraved ring located under the Earth. Maurice [68] gives the value 29d 12h 44m 33s for the synodic month, but this might be a typo, and I don't know if this period is inscribed on the clock.

This completes the description of the main features of the moving sphere.

3.2 How did Passemant compute the astronomical gears?

It is possible to say something new about how the astronomical gears were designed. Passemant's problem was to picture the motion of the planets, together with the Moon, and following the best data he had at his hands. His first thought must have been to decide how to display these motions. There are many ways to show the motions of the planets, and he chose to put them in a glass sphere. The second choice concerns the kinematic chains. One can for instance obtain first the motion of Mercury, then slow it down to Venus, and so on, until Saturn, which was the last planet known to Passemant. But it is also possible to use one motion and derive several other motions from it. At some point, one has to make a choice. In addition, Passemant had to decide how to integrate the motion of the Earth on its tilted axis, of the Moon, and in particular of the Moon's latitude. Once he came up with a layout, he had to find the adequate gears.

3.2.1 Splitting the problem in simpler problems

Eventually, Passemant (or Dauthiau) chose to have a base motion of 48 hours, and to derive the various other motions from this base motion. But in fact, the initial problem was split in a number of quasi-independent simpler problems:

1. obtain the motion of the Moon from the base motion;
2. obtain the motion of Mercury from that of the Moon;
3. obtain the motion of the Earth from that of Mercury;
4. obtain the motion of Venus from that of the Earth;
5. obtain the motion of Mars from that of the Earth;
6. obtain the motion of Jupiter from that of the Earth;
7. obtain the motion of Saturn from that of the Earth;
8. obtain the motion of the Earth on its axis from its orbital motion;
9. obtain the draconic month from the synodic month.

These problems were almost independent, except that there were some space and layout constraints. I am stressing that these problems can or cannot be made independent. For instance, obtaining the motion of Mercury from that of the Moon can either be based on the ratio of the actual revolutions of Mercury and the Moon, or, and this is in principle better, it can be based on the ratio between the actual revolution of Mercury and the computed revolution of the Moon. This is not exactly the same, but the latter solution implies that the first motion, that of the Moon, is obtained before that of Mercury.

I wrote previously that although the ratios corresponding to the revolutions are sometimes very daunting, for instance $\frac{96326276409}{3261914900}$ for the synodic month, this does not mean that Passemant ever manipulated these values directly. In fact, because he subdivided the initial problem into smaller problems, he had to work not with the final ratios, but with ratios such as between Mercury and the tropical month, or between Jupiter and the Earth. The actual ratios he implemented in his clock are given in the column at the right of figure 7, whereas the middle column gives two possible targets, one only based on astronomical data (or rather on the periods published by Passemant in 1738 [78]), and one based on astronomical data, but taking into account the errors introduced by previous gears and trying to compensate them.

Ratio	Targeted	Implemented
tropical month/48h	$13.660804\ldots$	$\frac{224037}{16400} = 13.660792\ldots$
Mercury/trop. month Mercury/trop. month*	$3.219724\ldots$ $3.219727\ldots$	$\frac{8484}{2635} = 3.219734\ldots$
Earth/Mercury Earth/Mercury*	$4.151987\ldots$ $4.151978\ldots$	$\frac{24123}{5810} = 4.151979\ldots$
Venus/Earth Venus/Earth*	$0.6151929\ldots$ $0.6151927\ldots$	$\frac{1239}{2014} = 0.6151936\ldots$
Mars/Earth Mars/Earth*	$1.8807532\ldots$ $1.8807527\ldots$	$\frac{2492}{1325} = 1.8807547\ldots$
Jupiter/Earth Jupiter/Earth*	$11.856765\ldots$ $11.856762\ldots$	$\frac{4802}{405} = 11.856790\ldots$
Saturn/Earth Saturn/Earth*	$29.428587\ldots$ $29.428579\ldots$	$\frac{206}{7} = 29.428571\ldots$
sidereal day/mean day	$0.997269\ldots$	$\frac{365}{366} = 0.9972677\ldots$
drac. month/syn. month	$0.921502\ldots$	$\frac{3087}{3350} = 0.9214925\ldots$

Figure 7: Targeted and implemented ratios. The values marked "*" are the target values based on already implemented gears, whereas the other target values are those based on the periods Passemant gave in 1738 [78].

3.2.2 The target values

The first issue is therefore that of the target values. What values did Passemant choose for the revolutions of the planets? He may in fact have used several sources, but one that we may start with are the values given in Passemant's treatise on the construction of a telescope, published in 1738 [78] (figure 8) and which I have mentioned in figure 7.

Revolution	Value (y/d/h/m/s)	Value (days)
Tropical month	27d 7h 43m 7s	27.3216087 . . .
Mercury	87d 23h 14m	87.9680555 . . .
Venus	224d 16h 40m	224.694444 . . .
Earth	365d 5h 48m 50s	365.242245 . . .
Mars	1y 321d 16h 20m	686.930555 . . .
Jupiter	11y 312d 20h 12m	4330.59166 . . .
Saturn	29y 156d 7h 31m	10748.56319 . . .

Figure 8: Passemant's revolutions given in 1738 [78]. The decimal values are my additions. Note that "year" means 365 days and 6 hours (a Julian year), not a tropical year.

These values were of course themselves obtained from other sources. For instance, the tropical month may come from Ozanam [77], but some of the other values are possibly corrupted. For instance, for the revolution of Mercury, earlier sources are more likely to give 87d 23h 15m or 87d 23h 16m, instead of 87d 23h 14m.

Some of the values may have been taken from earlier works on moving spheres. The draconic month of 27 days 5 hours and 6 minutes (27.2124999… days), for instance, may have been taken from Pigeon [85], Fortier [44], Bion [11] or another author. But some values also differ from these sources. The revolution of Saturn taken by Passemant in 1738 is not the same as that used by Pigeon. And in Cassini's tables [15] we find the same value of the synodic month as that used by Passemant, 29 days 12 hours 44 minutes and 3 seconds (29.530590277 days).

I am not sure about the source of the revolution of the Earth. Bion [11, p. 68], in 1728, and already in 1700, gave 365d 5h 48m 45s, a value that seems to go back to Tycho Brahé. Cassini in 1721 gave 365d 5h 48m 55s. The more correct value 365d 5h 48m 48s only seems to have been used at the end of the 18th century. By choosing 365d 5h 48m 50s, Passemant may have taken some middle value.

There is however another source for the target values, namely the clock itself! The rings of the sphere carry engravings of the periods, and these values all differ from the above ones published in 1738. These values are given in figure 9. It would seem that Passemant aimed at these values and the periods produced by his gear ratios are close to those marked on the sphere. In fact, for Mercury the difference is less than a second, for Venus it is less than 2 seconds, for the Earth it is a little more than 3 seconds, for Mars it is about 11 minutes, for Jupiter it is about 2 hours and for Saturn it is a little bit more than 5 hours.

Revolution	Value (y/d/h/m/s/t)	Value (days)
Mercury	87d 23h 14m 15s 45t	87.9682378 ...
Venus	224d 16h 40m 26s 3t	224.694745 ...
Earth	365d 5h 48m 55s 19t	365.242306 ...
Mars	1y 321d 16h 31m 59s 38t	686.938884 ...
Jupiter	11y 312d 22h 27m 50s 31t	4330.68600 ...
Saturn	29y 156d 12h 46m 40s 31t	10748.78241 ...

Figure 9: Passemant's revolutions given on the sphere itself [68]. The decimal values are my own. I am using "t" for thirds (‴). I didn't give a value for the tropical month, but it too is possibly given on the clock.

Of course, one might be surprised by the high accuracy of the values given in figure 9. In the mid-18th century, the revolution periods were not known with such an accuracy. But even if these values let one believe of an accuracy that didn't exist yet, they raise the question of their sources. Where did Passemant find these values? One idea would be to assume that Passemant took some figures somewhere, perhaps from recent astronomical tables, then perhaps computed some average between competing values, and then converted these figures to days, hours, minutes, etc., but not taking into account the fact that at some point the digits became meaningless. I do not believe that the periods engraved on the clock represent actual astronomical knowledge.

There is however yet another possibility to consider, namely that Passemant had values engraved which are close to the ones he implemented, either because he wanted to show that his gear ratios give good results, or because he meant to show the actual implemented values and computed them incorrectly. This might explain why the engraved periods can't seem to be found anywhere.

And indeed, I believe that this answers the question. I believe that the values engraved on the clock are not the target values, but are meant to represent the actual revolutions on the clock. But why are they then not identical to the values I gave in figure 7? I believe that Passemant got the computations wrong. For instance, in order to compute the revolution of Mercury, Passemant may have taken approximations of $\frac{8484}{2635}$ and $\frac{224037}{16400}$ and multiplied them, and multiplied again by 2 (because of the base motion of 48 hours), instead of computing first the exact fraction. If Passemant had computed

$$3.2197342 \times 13.660792 \times 2,$$

he would have obtained about 87d 23h 14m 15s 48t, which is almost the engraved value. Perhaps Passemant computed this product slightly differently or rounded some intermediate result, and got 45t.

For the Earth, he may have computed

$$3.2197342 \times 13.660792 \times 2 \times 4.1519793$$

which gives 365d 5h 48m 55s 9t. Again, we almost get Passemant's value, and he may again have done the computation slightly differently.

All this leads me to conclude that Passemant very likely took the 1738 values for his targets, and engraved approximation of the actual periods produced by the clock, but thinking that what he engraved were the actual periods on the clock.

3.2.3 The choice of the ratios

It is not known how Passemant found his ratios. It seems that he wanted to avoid having wheels with more than 100 teeth and the largest number involved in the astronomical gears seems to be 103. Passemant clearly did not use the method of continued fractions, which would have given more accurate results, but also would have required discarding some fractions because they contain too large primes. He also did not make use of complex epicyclic constructions but kept with simple gear trains.[10]

[10]Daumas's biographical notice mentioned earlier [22, p. 347-350] sheds some light on Passemant's real capabilities. He observes that Passemant used some fantastic figures

Finally, we can observe that the largest integer involved in the chosen fractions is 224037 and this means that if Passemant didn't manipulate numbers larger than that value, he only needed a table of prime numbers up to 467. Such a table can easily be constructed in a short time, and I had myself computed by hand a table up to 2500 more than 40 years ago.

We can see that Passemant could have done better here and there. For instance, for the revolution of Jupiter, with the same number of wheels, Passemant would have obtained a more accurate result with the ratios $\frac{76}{23} \times \frac{61}{17}$.

There are in fact two ratios which are more complex than the others: the ratio between the tropical month and the base motion, and the ratio between the Earth and Mercury. For the latter, Passemant used three pairs of gears $\frac{a}{b} \times \frac{c}{d} \times \frac{e}{f}$ and he could hardly have done better with his constraints.

For the tropical month, it is likely that Passemant first tried to obtain the sought ratio directly, then with two pairs of gears, then three, etc. Eventually, he came up with five pairs of gears. However, there are good solutions with only three pairs, for instance $\frac{10}{11} \times \frac{65}{12} \times \frac{86}{31}$, $\frac{11}{8} \times \frac{91}{8} \times \frac{69}{79}$, $\frac{11}{14} \times \frac{61}{23} \times \frac{59}{9}$, etc., or some variation of these values.

All this suggests that Passemant proceeded in an unsystematic way, and not finding a solution with three ratios, moved to four, then to five.

As mentioned above, the question also arises whether Passemant targeted the real astronomical ratios, or if he targeted those provided by the clock. For instance, when attempting to approximate the ratio between the revolution of Mercury and the tropical month, Passemant could have aimed at the real ratio, based on the astronomical data, or (and that would have been better) he could have aimed the ratio between the astronomical revolution of Mercury and the tropical month provided by the clock (and not the actual astronomical one). These two values are slightly different. The comparison between these two targets does however not allow for a plain conclusion. The chosen ratio is sometimes closer to the astronomical ratio, and sometimes it is closer to the ratio Passemant should have pursued. Of course, trying to take into account the real clock ratios (marked "*" in figure 7) would have prevented the accumulation of a number of

when describing the magnification of his instruments, and that his reasoning was not that scientific. This opinion is repeated by King [57, p. 285]. It also should be put in perspective with the too accurate values engraved in the moving sphere. This shows at the very least that Passemant was neither a mathematician nor a theoretician. He was above all a very able mechanician.

errors. However, if Passemant had aimed at the already computed clock ratios, this would also mean that he would first have had to compute the gears of the Moon, of Mercury and of the Earth, before those of the other planets, and it is not sure that he proceeded that way.

This may also explain why Passemant ended up with a bad value for the revolution of the Earth, a value perhaps too hastily criticized by Janvier. Passemant obtained 365d 5h 48m 58s, which is off by 8 seconds from the value he gave in 1738, which is actually very good, and much better than other values given at the time. But in spite of this, Passemant's approximation of independent problems naturally leads to this large difference. In fact, if Passemant had even been closer to the real Earth/Mercury ratio, for instance if he had taken 4.15198, the resulting revolution of the Earth would have been worse on the clock, even though he would have been closer to the astronomical ratio. This counter-intuitive result follows because by getting closer to the real target ratio, Passemant would have been farther away from the ratio he should have targeted. Moreover, concerning the Earth, Janvier objects that Alexandre had given the ratios $\frac{50}{7} \times \frac{69}{8} \times \frac{83}{14}$ from a base motion of 24 hours. Alexandre's ratios lead to a revolution of 365d 5h 48m 58.77...s, given that he had targeted 365d 5h 49m. All this shows that Janvier's critique was certainly at times excessive, first because Janvier missed the fact that Passemant knew of a good (at the time) value for the revolution of the Earth, and second because Janvier did not understand the implications of subdividing the problem into subproblems. It would be a bit like writing that there is a problem using a ratio such as $\frac{96326276409}{3261914900}$, when in fact Passemant was only using such a ratio implicitely.

3.3 The long term accuracy of the astronomical gears

In the 1754 report on the clock [24], it is said that the planets will not be wrong by more than one degree in 3000 years. Later Janvier [55, p. 106] observed that this is surely a typo, because the clock itself contains an engraving about a "2000 year accuracy."

Now, what does it mean for a planet to be wrong by one degree in 2000 years? We can do some calculations. For Mercury, in 88 days, such an error would amount to $\frac{\frac{88}{365.25}}{2000} \approx 0.00012$ degree in one revolution. But how long does it take to move by that amount? We find that the time is

$$t \approx \frac{0.00012}{360} \times 88 \approx \frac{88^2}{270000000} \approx 0.00003 \text{ days}$$

This represents about $\frac{88^2}{188000}$ minutes, or $\frac{88^2}{3125} \approx 2.5$ seconds.

Similarly, for Saturn, one degree in 2000 years corresponds to an error of about 10 hours in a 10749 days revolution.

For the Moon, this corresponds to an error of about 0.25 seconds.

For Mercury, if Passemant aimed at 87d 23h 14m, he finds himself with a revolution wrong by 17 seconds. If he aimed 87d 23h 15m, he is wrong by 43 seconds. One can hardly consider that the error on the revolution of Mercury is smaller than 2.5 seconds. The inscription on the sphere is therefore certainly not correct, and in their report Camus and Deparcieux have probably decided to show some complaisance towards Passemant.

The motion of the Earth, although off by 8 seconds from the (probable) target value, does not go past one degree in 2000 years. The exaggerated statement of accuracy therefore mainly concerns Mercury and the Moon.

4 The other parts of the clock

In the previous section, I showed that Passemant's celestial sphere (or orrery) is certainly not as complex as usually described, and can be understood, albeit perhaps not in five minutes and probably not with a 3D animation. Now, what about the other parts of the clock? Unfortunately, almost nothing has been written about the going work, the striking works or the calendar gears, and all we have are some glimpses through glass panels and hints by Janvier [56].

According to some descriptions, the celestial sphere can be put out of mesh with the going work, and it can then be moved forward more rapidly using a crank. This does immediately raise the matter of the time indication. The going work probably causes the updates of the calendar work, and if the celestial sphere moves independently, the time of the heavens is no longer the one displayed on the clock. Is there then another display? And is there then a way to go back in time to resume the normal course of events? Berthoud vaguely mentioned that there are three unmeshing possibilities. The most detailed description of these unmeshings was in fact

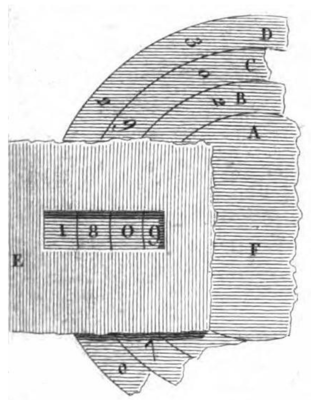

Figure 10: The display of the year [55].

given by Maurice [68]. He writes that there are three levers for that purpose. The first lever is supposedly used to shift the anchor and the clock can then be set to the right time. If this is true, it would be like freeing the clock from the escapement and let it run faster when it is slow. Perhaps this is indeed what is done, but it recalls ancient clock settings, when more sophisticated devices were not yet known. The second lever separates the sphere from the going work. The sphere can then be moved with a crank. One turn corresponds to 12 hours. There is also a dial with makes one turn in 30 days. It is therefore possible to go back as much as one went in the past or future, as long as one does not move by more than 30 days (60 turns). Actually, one can move the sphere more, but then one has to keep track of how many turns were made beyond 60, that it, also keep track of the full turns of the dial, which are not indicated. The third lever serves the same purpose as the second, but the rotation is faster. Maurice does not say to how much one turn corresponds. Of course, all this should be detailed during the upcoming restoration.

Some commentators and curators have written about the possibility for the clock to predict eclipses, but this would only be possible if the sun and the Moon were shown with the right apparent diameters, which is not the case. Such statements are apparently based on a description by Dauthiau which was reproduced by Berthoud. Dauthiau's statements on eclipses are unfortunately not correct. Passemant's clock can not indicate eclipses in a precise manner. It may sometimes suggest them, or infirm them, but with a large margin of uncertainty. The clock does moreover not take into account the irregular motion of the Moon, which renders such eclipse predictions much less reliable than those obtained by the astronomical tables of the time. This is in fact true for the great majority of the astronomical clocks.

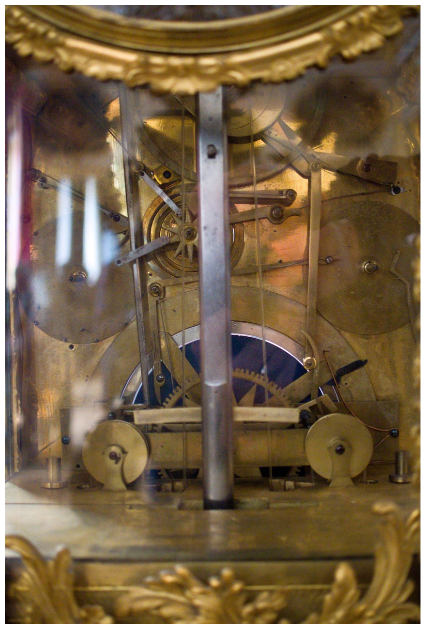

Figure 11: The calendar mechanisms. (Photograph: Bob Holmstrom, with permission)

The clock mechanism is made of a going work, with a pendulum (and weight), and two spring driven striking works (with fusees). The clock strikes quarters and the strikings can be repeated. Such mechanisms are well known, but the one on Passemant's clock is not documented. The principle of the repetition is supposedly borrowed from Julien Le Roy.

According to Berthoud, the pendulum is a seconds pendulum, that is it would perform a complete oscillation in two seconds. This pendulum is compensated, apparently also following a construction imagined by Julien Le Roy. Some details on the compensation were given by Maurice [68].

On the front of the clock, we can recognize the day of the week, the day of the month, the month and the year. The year is merely obtained by four concentric and coplanar rings (figure 10). It is in fact an odometer, stabilized in the back by four 10-pointed star wheels. There is no point getting excited[11] by the seamless passage to 2000, and such a mechanism can even work beyond 9999. If the clock does still exist, one will merely have to add a 1 at the left of the newly appeared 0000.[12] The clock takes into account leap years, but probably not the common secular years such as 1800, 1900, 2100, etc. These years will probably require a manual adjustment, but this never happened, because the clock was in working order neither in 1800, nor in 1900. The day of the month indication (quantième) supposedly also takes care of the month lengths.

The clock also displays the phases of the Moon, but probably in a way independent from that in the celestial sphere.

The clock also (!) shows the time, both solar time and mean time. On this, we know from Janvier [56, p. 230] that Passemant's construction was depicted in Lepaute's treatise [65]. Figure 12 shows this construction.[13] On the axis of the minute hand wheel, there is a small wheel AD whose rotation is commanded by the equation rack, itself resting on the equation cam. This wheel moves a quarter of a turn right or left and is attached to a hand showing the equation of time. The wheel GL moves with the minute hand and transmits its motion to wheel M which moves counterclockwise. Again, because of pinion F, wheel IK moves clockwise. However, because pinion F is attached to wheel AD, wheel IK oscillates around the mean time to show the solar time.

For the perpetual calendar and the phases of the moon, Janvier writes that Passemant followed Enderlin's construction which is described in

[11]Comments by journalists and even curators about the marvel of a clock working until 9999, or rather "programmed to work until 9999", are simply ridiculous. A car odomoter is then also programmed to work until, say, 999999 kilometers, and in fact much more. It is as ridiculous as stating that a calculating machine was designed to compute up to its maximum limit. Passemant's clock can be set to 9999 for fun and let reach 0000 without harm, and perhaps this is what should be done for those who maintain that there is something extraordinary here. In fact, we merely have a basic counter, and it is the simplicity that leads to this craze. "Wow, you know how to add 1 to an integer? Then, you wanted to count up to 999999999999?"

[12]However, what should be checked is whether the counter is reversible. Does it work both ways? Can it count time backwards? Some carry mechanisms are not reversible.

[13]Lepaute's figure was reprinted, slightly adapted, by Moinet in 1848 [73, plate XX], who analyzed the construction. A more recent analysis, also based on Lepaute's drawing, was given by White [102, p. 62-65].

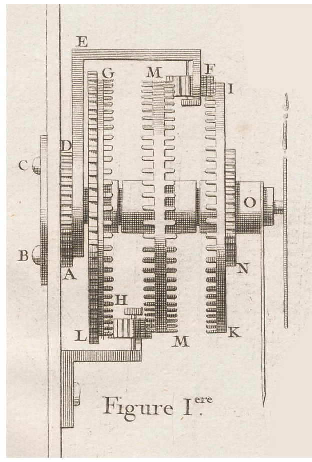

Figure 12: Passemant's construction for the equation of time, mean and solar time [65, pl .XV].

Thiout's treatise [98]. Figure 13 shows this construction. Enderlin's clock has a wheel making one turn in 365 days and 6 hours, and carrying the equation cam. This wheel is advanced by an endless screw whose motion is provided by the striking work. The motion of this screw is moreover transmitted to the day of the month hand, as well as to the lunar disk. The day of the month advances by one unit every 24 hours. The lunar disk makes one half turn in 29 days 12 jours 45 minutes and has 90 teeth. The annual wheel also carries the names of the months and carry pins which are used to reset the day of the month. A special provision is used for the end of February and leap years.

In Passemant's clock, the months and other calendrical indications are shown in windows, but they are probably still triggered by pins on the annual wheel.

It is clear that none of all this is particularly complex, and yet none of this has ever been seriously documented.

5 Copies of the clock

Several copies of Passemant's clock have been made, some of them shown in figure 14. Most recently, a copy was sold at Christie's, London, 23

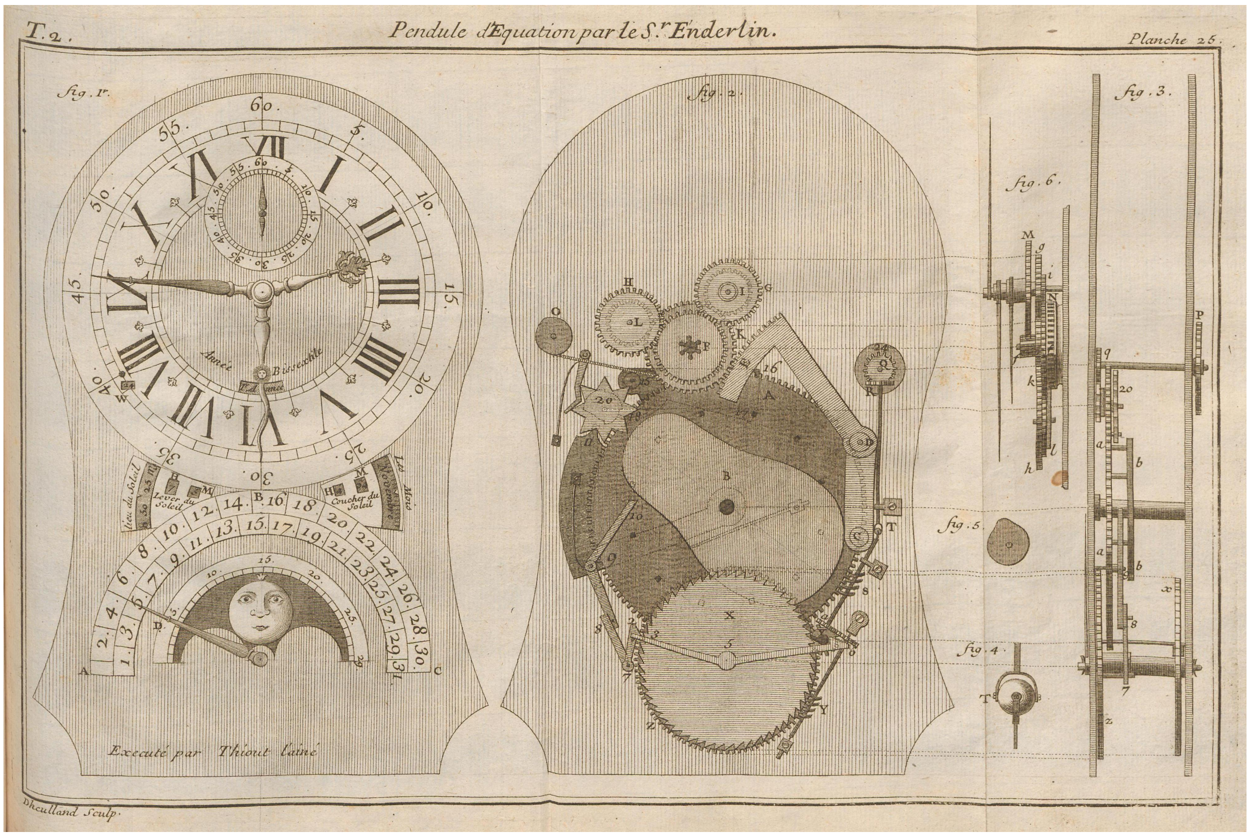

Figure 13: Enderlin's equation clock [98, vol. 2, pl. XXV].

May 2019. Some of these replicas are obviously unfaithful to the original clock, and it is likely that none of the replicas actually replicates the full mechanisms. It seems that the first copy was made around 1860 by Carl Dreschler, Charles Crozatier and Charles Couët for Richard Seymour-Conway, 4th Marquess of Hertford (1800-1870). Couët was the clockmaker and the gears of his celestial sphere were described by Redier in 1860 [89]. The sphere appears to be a much simplified version of Passemant's sphere. Payne [82, p. 168] argues that the bronze molds for this copy and others were made in 1833 when Passemant's clock was returned to Versailles.

This copy was part of the collection of Sir Richard Wallace, Lord Hertford's illegitimate son, and was located at the *2 rue Laffite* in Paris [101, p. 237, 265]. When Lady Wallace died, Sir John Murray Scott (1847-1912), Sir Richard Wallace's secretary and later advisor to Lady Wallace, inherited her art collection, with the exception of the works of art on the ground and first floors of Hertford House, London, which became the Wallace Collection [53, 54, 16]. After his death, his family bequeathed the rue Laffitte apartment to Lady Victoria Sackville (1862-1936) who in 1914 sold the entire rue Laffitte collection (with the house) to the Paris art dealer Jacques Seligmann (1858-1923). It is not known what became of the replica after the sale, and it may have been kept by Seligmann's heirs Germain Seligman(n) (1893-1978) and François-Gérard Seligman (1912-1999) but in 1996 it was sold at Marshall Galleries, Los Angeles to the owner who sold it at Christie's, New York, on 19 April 2016 (lot 200).

The bronze molds were later used by other cabinet-makers for other replicas.[14] In 1885, Carl Schweitzer, a Munich clockmaker [93, p. 746], made a copy for the castle of Herrenchiemsee in Germany [57, p. 286], [94], perhaps the most faithful of all the replicas. In does in particular replicate the marble pedestal. According to Seelig, it is likely that at least the case of the replica was made in France [94, p. 99].

Another copy was made in 1893 by Alfred Beurdeley, at least for the bronze structure (figure 14) [70, p. 97], [69]. This replica was shown at the 1893 international exhibition in Chicago [59, p. 26-27] and auctioned in 1895 [8, p. 196].

At least two copies were made by François Linke, one probably before 1900 and a second between 1910 and 1912 [81, 82]. One of the copies (sold

[14] An excellent source for the making of bronze molds and related techniques is Verlet's book [100].

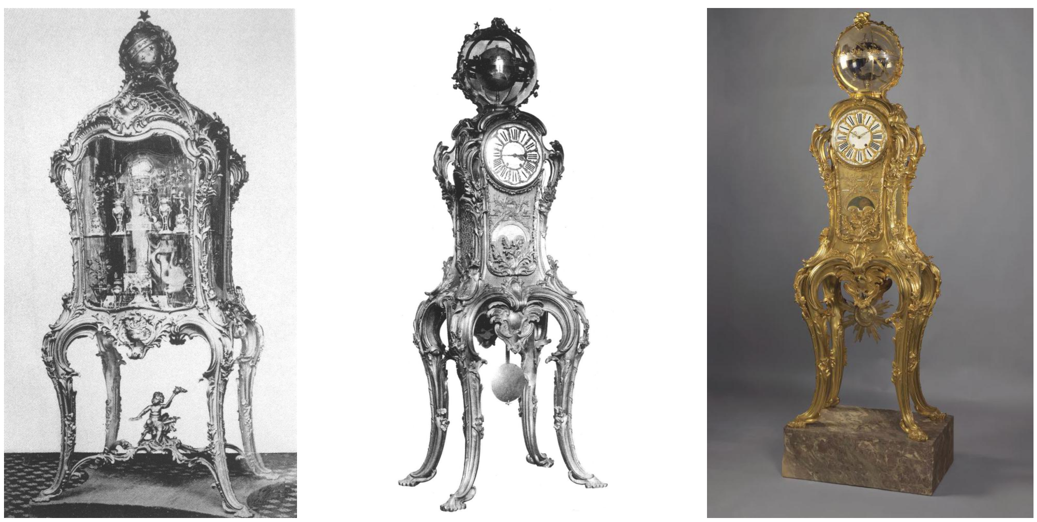

Figure 14: Left, Millet's clock inspired case ([70, p. 175], 1889 exposition universelle, photograph published by Victor Champier), middle, Beurdeley's replica (1893) ([70, p. 97], from the 1895 auction catalogue, lot 37), and, right, a copy by Linke (Courtesy of Adrian Alan Ltd., www.adrianalan.com, London).

at Sotheby's, Paris, 20 September 2016 [95], and probably earlier Bonhams, San Francisco, 7 June 2004) contains a starry sphere within the globe but the copy illustrated by Payne does not [81, p. 207]. In 1905, Linke had bought a bronze mold from Dostal (illustrated in [81, p. 365]), bronzier-clockmaker in Paris, who had it himself obtained from Millet.[15] A third copy, attributed to Linke, was auctioned at Sotheby's Hong Kong in October 2015 (*Age of Elegance: European Paintings, Furniture and Sculpture*), but it was not mentioned by Payne [81]. It is however not clear who constructed the clockworks of Linke's replicas, as it is to be assumed that he only took care of the bronze parts. In 1928, Linke also offered to sell one of the copies to the King of Egypt but this did not work out [81, p. 210]. In any case, plans for the moving sphere are held in the Linke archives [81, p. 364].

Another replica, or maybe one of the previous ones, was possibly shown by Georges Dufayel, owner of the Grands Magasins Dufayel, in a "Salon Louis XIV" at the Paris 1900 Exposition universelle.

Some of the replicas seem to contain a terrestrial sphere, or perhaps even mockups. In at least one of Linke's replicas, the calendar mechanism is non functional and kept on a constant date. And as a rare glimpse into the working of one the replicas, the back of Couët's calendar mechanism shown in the auction catalogue appears entirely different from Passemant's.

6 Is there anything left to be done?

Now, what will happen next? The clock was removed for restoration in December 2021 in order to be displayed in full working order for the upcoming exhibition on Louis XV, set to start on October 18, 2022. It will be restored at the National Centre for Research and Restoration in French Museums (C2RMF) located at the Louvre, by a team of supposedly 20 restorers, some for the mechanical part (Ryma Hatahet, Jean-Baptiste Viot, Serge Rukwavu, Leslie Villiaume and perhaps others), and some for the

[15] Millet had himself made a case inspired by Passemant's clock (figure 14), but which was not really a replica. It was shown at the 1889 exhibition in Paris [50], [49, p. 418], [84, p. 674]. An illustration of that case was given by Mestdagh [70, p. 175]. See also Payne [81, p. 210].

bronze parts.[16] The press release [18] and several articles published in the newspapers *Le Parisien* and *Le Figaro* are quite dithyrambic and often contain inaccuracies. For instance, the press release mentions the "29 astrological decans of the moon," when in fact no such thing exists. It is therefore already clear that what is written on the clock by various curators and journalists can't be taken at face value. The newspapers copy the information from the press release, and the curators produce a hodgepodge of dubious information based on misunderstood historical writings, but not on any serious analysis.

I therefore strongly hope that this restoration will be the opportunity to finally provide a long-wanted real scientific documentation of the clock. The present sketch of the clock is only a first step, and it is absolutely necessary to go much beyond such an analysis and provide a thorough description of the clock, such as perhaps never a clock was documented in a French Museum. I have analyzed the astronomical gears and given some hints at how the other parts of the clock work, but I have not given the actual layout of the gears. Even if my figures are probably correct, my work is not a thorough documentation of the clock. Much more has to be done. And even if the exact layout of the gears is given, even if plans are provided, there will remain to document not only these things, but also all the details. In fact, every tooth of every wheel should be documented. I cannot comment on the shape of teeth, I cannot comment on what has been repaired in the past, I cannot comment on the accuracy of gear cutting in this clock. I can also not comment on the amount of backlash, or on possible errors due to backlash. Janvier wrote that the combination of

[16]On February 11, 2022, the director of the castle of Versailles, Laurent Salomé, sent me several documents mentioning these three restorers, as well as John-Mikael Flaux who will supposedly make plans of the clock. Four "experts" are also mentioned and must have written reports (which I don't have) at some point: Stéphane Girardot, a horology antiquarian, Philippe Prutner, a clock restorer, Marc Voisot, a clock restorer, and François Simon-Fustier, a clock restorer also developing an activity of 3D modelling using the SolidWorks software (with his employee, Sébastien Lucchetti). The restorer Julie Schroeter is involved for the bronze parts, but there are probably other restorers not mentioned in the documents provided by the castle. It is noteworthy that no researcher, no scientist, no mathematician or astronomer or other expert of astronomical clocks is involved, in an intervention that claims to be beyond perfection. Moreover, Mr. Salomé did not answer my request for the identity of the curator writing on the clock in the upcoming catalogue. I was also not given the full preliminary study of the clock, a 70 pages document of which I only received the first two pages.

gears produced a large angular error, but in order to ascertain this, one needs to know the layout of the gears and the accuracy with which they were cut. Errors on one wheel get multiplied if the ratios introduce accelerations, and it remains to be seen if and where this takes place. These are only some of the things that need to be addressed if a scientific analysis of the clock is to be conducted.

Of course, Passemant's clock has been restored in the past, and in particular around 1950 by the clockworker Pierre Bécard [91] and around 1989 by the Versailles castle clockworker Daniel Mornas [7].[17] In 1951, the clockworker Mongruel wrote that the clock was beyond repair [74, p. 87]. But even if it was restored, the archives of the castle of Versailles do not seem to contain any plans and no detailed accounts of this restoration. This is of course what was commonplace then, and what still is commonplace nowadays, even in great museums. Clocks are restored, polished, repaired, etc., and then are shown to the public, without any technical details, as if, as I said above, the public were not interested or could not understand how a clock works.

A modern restoration should involve three categories of people: curators, restorers and researchers, and should in particular have as aims to put the object (not necessarily a clock) in some standard condition, perhaps (but not necessarily) in working condition, but also to document the object fully, somehow trying to restore not only the object, but also its creative process. Documenting a restoration is therefore much more than documenting how parts were cleaned, how some of them were repaired, and so on. It is also about making plans, counting teeth, computing ratios, taking exhaustive photographs, etc. In fact, a full documentation should make it possible for anyone to reconstruct the clock, at least digitally. It is therefore not sufficient to provide only some gear ratios, or some final ratios (such as those of the revolutions of the planets), but also all the underlying layouts. Dimensions are important, and the restoration should not be about keeping secrets, neither for the castle of Versailles, nor for the restorers. A complex mechanism is worth explaining, not merely showing from the outside. This means that it must be possible to compare the details of the actual celestial sphere with my hypothetical reconstruction, but

[17]D. Mornas was in charge of the Versailles clocks from about 1982 until 2001. He was followed by Bernard Draux until 2020, himself followed by a team (J.-B. Viot, R. Hatahet, S. Rukwavu and L. Villiaume).

also that we should know exactly how the perpetual calendar works, how the striking works work, how the pendulum is compensated, and so on, and of course how these components are constructed. At the very least, a decent restoration should provide a complete and logical naming of the parts, and each part should be photographed independently on graphed paper. There should also be XRF metallurgic analyses. And who does what should also be documented. And of course, all this documentation should be made public, and not be available only to the curators. And if a 3D model is made, that model should be made public in a common exchange format such as STEP, and not merely in the form of prerecorded animations or interactive applications without access to the underlying model.

More generally, whenever such an intervention takes place, curators should first gather with scientists and restorers, and ask themselves what should be done. The obvious answer for a clock is to restore it and make it work again (although this is not always the purpose), but this is only one side of the coin. If a clock such as Passemant's clock is only restored and put back in its room to show one of the glories of Louis XV, then there will still be a lot of hidden (and therefore lost) knowledge. Researchers on complex clocks, or merely horology historians, will not be able to make any progress, and the little technical knowledge usually found in restoration reports will be of almost no use to them. Therefore, curators should also make all they can to fathom the needs of the scientific community, and to find out what should be done beyond merely putting such a clock in working order.

We will find out in October 2022 if that ideal modern documentation comes into being.

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