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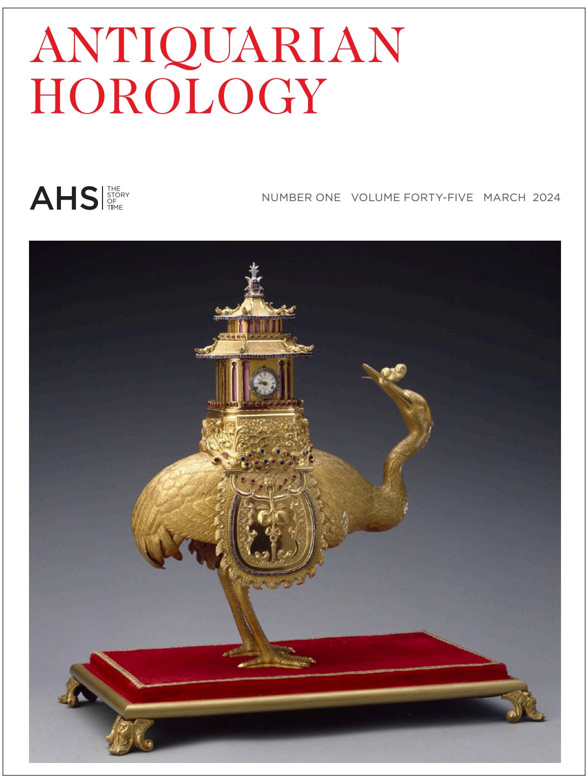

The March 2024 issue contains five articles:

Front cover: More than twenty clockwork treasures collected by Chinese emperors have travelled from the Palace Museum in Beijing to be displayed in the Science Museum, London. Photo © The Palace Museum.

Experimenting with the pendulum: the work of Tito Livio Burattini (1617–1681)

Augustin Gomand*

The main studies related to the first pendulum clocks focus on the prototypes invented by Christiaan Huygens, described in Horologium *in 1658 and in* Horologium Oscillatorium *in 1673, as well as on the commercial models made by Salomon Coster and reproduced by various clockmakers in Europe. However, others tried to apply the pendulum to clocks in parallel to Huygens's work or inspired by it. The clocks resulting from this are interesting because they were conceived with an experimental and scientific purpose, to experiment with the pendulum oscillator and to test its regularity; they may present atypical layouts which deviate from the models proposed by Huygens. Several brief descriptions of such experimental clocks designed by the Italian-Polish engineer Tito Livio Burattini (1617–1681) offer an opportunity to analyze his original constructions and to understand how they fit into the scientific context of the time and are linked to the personality of this inventor. This article is part of the Simon Le Noir Project.*

Introduction

Early pendulum clocks have been the subject of regular discussion for decades. While the main lines of this history have been known for a long time, unpublished documents have recently been rediscovered that allow us to refine our perception of the historical and social context in which the pendulum clocks were invented and then commercialized.

Most articles on this subject focus on the scientific regulators designed by Christiaan Huygens and the domestic models manufactured and marketed by Salomon Coster. There are few studies on the other primitive pendulum clocks that were derived from these designs, conceived by independent clockmakers or scholars who had heard about the novelty or had occasion to see for themselves the new pendulum clocks built in Coster's workshop.

The Italian-Polish[1] engineer Tito Livio Burattini is one of those who, enthusiastic about the new invention of the pendulum clock, applied the pendulum very early to various forms of mechanisms, seeking to perfect its operation. His atypical constructions are described in previously unpublished letters that are presented in this article.

Burattini was an outstanding engineer who followed closely the scientific theories of his time and regularly exchanged letters with scholars throughout Europe. He came to consider the pendulum not only from a technical point of view but as the starting point of a universal scale of measurements that he proposed as early as 1675, more than a century before the metric system established after the French Revolution.

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1. Burattini was born in Italy but was naturalised as a Pole in 1658 by the king of Poland, John Casimir.

Tito Livio Burattini, a little-known engineer and experimenter

Tito Livio Burattini is still largely unknown to the general public, which is quite surprising when one considers the extent and diversity of his work and the links he maintained with many scholars throughout Europe. The first study dedicated to him, written by Antonio Favaro and published in 1896,[2] gathers most of his known correspondence. Burattini is also mentioned in some historical and scientific works of the nineteenth and twentieth centuries, but usually without going into any detail. More recently, Karolina Targosz and Ilario Tancon have examined his scientific work and his links with the Polish court.[3,4] The introduction to the recently published correspondence of Johannes Hevelius with Pierre des Noyers also presents some elements of synthesis on the life of Burattini and his role in the political and scientific life of the time;[5] other synthetic elements can be found in the work of Jean-Arcady Meyer.[6] We will take up here some of these elements which draw an accurate portrait of this person.

Biographical elements

Tito Livio Burattini (sometimes spelled Boratin, Buratin or Boratyni) was born in Italy on 8 March 1617. He spent the first years of his life in Venice where he studied science with Michele Peroni. In 1637, he was sent to Egypt where he carried out various studies during four years, in particular on the architecture of the pyramids and obelisks, by seeking to specify the unit of length which had been used to specify the dimensions of the pyramid of Cheops.[7] He was also interested in the floods of the Nile, of which he later gave a demonstration.[8] Back from Egypt in 1641, he stayed for a while in Germany, then went to Krakow where he met Stanislas Pudłowski, an eminent Polish scientist who had a physics laboratory.

It is impossible to describe Burattini's life without devoting a few lines to Pudłowski, who contributed significantly to his training and future achievements. Born in 1597, this Polish scholar studied in Krakow and Rome; during his three trips to Italy, he came into contact with most of the great scholars of the time, including Viviani and Galileo.[9] He had been recommended to Galileo in 1640 by Benedetto Castelli, one of his disciples, who had known Burattini in Rome and said he had 'never met anyone so concerned with Galileo's ideas' (*non ho trovato mai nessuno che con maggiore affetto e sincerite habbia celebrata la dottrina e l'alto sapere di V.S.*). Pudłowski is perhaps one of the last to have had the opportunity to meet Galileo personally and certainly one of those who benefited most from his teachings, and he invited other scholars to continue his work. It was even reported by Burattini that he owned all of Galileo's printed works as well as some of his manuscripts.[10]

Burattini worked with Pudłowski until the latter's death in 1645. He then traveled in Europe for two years before returning to Poland in Warsaw in 1647, under the reign

2. A. Favaro, 'Intorno alla vitae ed ai lavori di Tito Livio Burattini fisico agordino del secolo XVII', *Memorie del Reale Istituto di Scienze, Lettere ed Arti*, XXV–8 (1896).

3. K. Targosz, *La Cour savante de Louise-Marie de Gonzague et ses liens scientifiques avec la France : 1646–1667* (Wrocław: Zakład Narodowy im. Ossolińskich, 1982).

4. I. Tancon, *La Scienzato Tito Livio Burattini (1617–1681), al servizio dei Re di Polonia* (University of Trento, 2006).

5. C. Grell and D. Mallet, *Correspondance de Johannes Hevelius – Tome III – Correspondance avec Pierre des Noyers, secrétaire de la reine de Pologne* (Turnhout: Brepols, 2020), pp. 23–33.

6. J.-A. Meyer, *Dei ex Machinis – vol.II* (Suresnes: les Éditions du Net, 2015), pp. 93–112.

7. Meyer, *Dei ex Machinis*, p. 93.

8. T. L. Burattini, *Nuova dimostratione dell'inondatione del Nilo*, quoted in Favaro, 'Intorno alla vitae ed ai lavori di Tito Livio Burattini', pp. 93–97.

9. A. Birkenmajer and S. Dickstein, *Coup d'œil sur l'histoire des sciences exactes en Pologne, in Histoire sommaire des sciences en Pologne* (Cracow: Drukarnia Narodowa, 1933), p. 13.

10. K. Targosz, 'Polski wątek w życiu i sprawie Galileusza "Galileo Galilei e il mondo polacco" Bronisława Bilińskiego (1969) z uzupełnieniami', *Zagadnienia Filozoficzne w Nauce*, vol. XXXII (2003), pp. 34–35.

of Ladislas IV, a sovereign who was very interested in science – he had ordered an astronomical telescope from Galileo himself. It was at this time that Burattini met Pierre des Noyers, secretary to Louise-Marie de Gonzague, Queen of Poland, who was to become one of his most faithful friends and collaborators.

John Casimir succeeded his brother Ladislas IV upon his death in 1648. During his reign, Burattini, who was very much appreciated by the court, was entrusted with various scientific, diplomatic and military missions and appeared as a very eclectic businessman. Thus, he was appointed architect to the royal court in 1652 and became responsible for the lead and silver mines of Olkusz and for the iron mines of Zawadow the following year.[11] During this period, he supervised the construction of the palace of John Casimir and also engaged in some creative scientific activities that will be detailed later. He was also appointed supervisor of the Cracow mint which he directed for some time with Paolo del Buono, another Italian scholar who will be discussed below, and then with Andreas Tympf.

Unfortunately, this last activity caused Burattini's downfall because, having minted considerable quantities of copper coins (the 'boratynki') to cope with the monetary crisis, he was accused by the nobility of having become fraudulently rich. He was summoned to present accounts to the Treasury Commission convened in Leopol in 1662 and charged with paying the wages of the troops, after the return of peace in Poland. Until 1667, several years followed when Burattini continued to mint an increasingly devalued currency that led the reign of John Casimir to a financial disaster and for which he was considered one of the main culprits.[12] The death of the queen and the abdication of John Casimir in 1667 deprived him of his most fervent supporters.[13] He ended his life miserably and died on 17 November 1681 in Cracow.

Burattini's main technical achievements

Although Burattini demonstrated his abilities and skills in several fields throughout his life, he is now mainly recognized for his wide-ranging scientific constructions. He had a laboratory and an observatory in the Mint of the Ujazdow Palace where he built scientific instruments and made astronomical observations. His numerous diplomatic missions in Europe also allowed him to get in touch with many French scientists and scholars, among whom Ismaël Boulliau, and with the Italian prince Leopold de' Medici and his brother, Ferdinand II de' Medici, Grand Duke of Tuscany, to whom he sent, and from whom he received, various scientific instruments and books; in August 1657 Burattini returned from Florence from where he brought back 'some mechanical niceties' (*quelques gentillesses de mécanique*) offered by the Grand Duke.[14] Burattini's most outstanding creations have been fairly well documented, even if none of them seem to have survived. We will describe here the ones that are not related to horology.

Burattini's first known achievement is an hydrostatic balance inspired by Galileo's. He must have made it before Pudłowski's death in 1645, since in his book *Misura Universale* (to be discussed later) Burattini explains that he had presented it to him.[15] This balance was constructed on the principle of the one Galileo had conceived in 1586 and described in a manuscript of which he had given a copy to Pudłowski. Burattini built a simplified version of it and of a more practical use, which he described in a first treatise. This manuscript was stolen from him when he traveled through Hungary shortly after 1645; after he settled in Poland, he wrote a second version, preserved in the National Library of

11. Meyer, *Dei ex Machinis*, p. 94.

12. Grell and Mallet, *Correspondance de Johannes Hevelius*, p. 26.

13. Meyer, *Dei ex Machinis*, p. 95.

14. P. des Noyers, *Lettres de Pierre Des Noyers, secrétaire de la reine de Pologne, Marie-Louise de Gonzague, pour servir à l'histoire de Pologne et de Suède de 1655 à 1659* (Berlin: E. Bock, 1859), hereafter *LPDN*, letter CXXIII, p. 342.

15. T. L. Burattini, *Misura Universale [...]* (Vilna: Padri Francescani, 1675), *Proemio*.

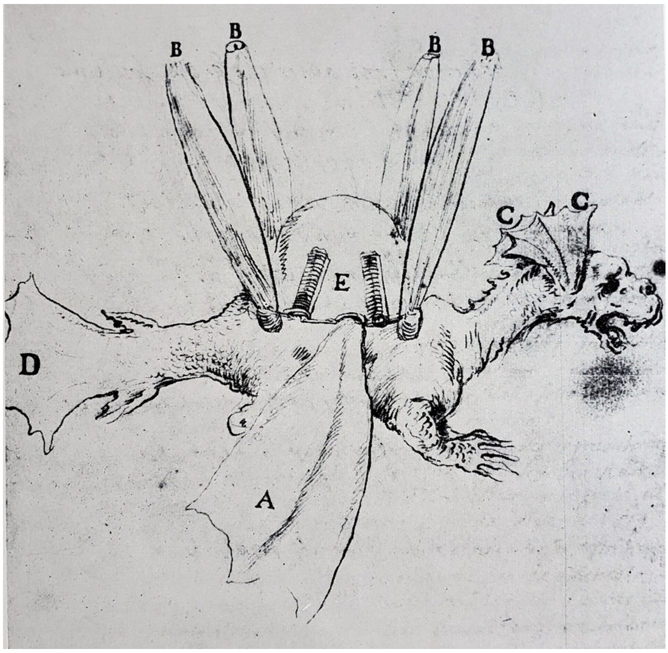

Fig. 1. Burattini's 'flying dragon'. Archives de l'Académie des Sciences, Dossier Fermat, Annexe. Public domain. The main wings (one shown as A) serve to propel the machine forward and to support it. B are four wings for support. C are two wings to aid propulsion. Tail D is for steering. E can be expanded and serves to prevent the machine from rushing.

France,[16] which was never published. This treatise was mentioned by des Noyers in his correspondence with Mersenne:

> He [Burattini] makes a balance which he believes (no one having explained it) to be that of Archimedes. He admits that the design is taken from a rather imperfect one by Galileo....[17]

It seems that des Noyers transmitted Burattini's manuscript to Roberval, which explains why it is preserved in Paris.[18]

Burattini's second notable achievement is also the one that occupied him the longest and for which we have several manuscripts by Burattini himself. It is a flying machine called 'flying dragon' which he worked on from 1647 to 1649. Like other *virtuosi* before him, including Leonardo da Vinci, Burattini wished to build a machine capable of rising into the air by the mere power of man. A representation of this machine can be seen in Fig. 1 from the treatise written by Burattini that he presented at the end of 1647 to King Ladislas IV. A copy of it is preserved today, which des Noyers had sent to Roberval, attached to a letter dated 4 December 1647.[19]

Burattini's dragon was a form of 'ornithopter' whose wings narrowed as it rose and widened as it fell.[20] Although it may seem like a joke now, this machine was quite successful in

16. T. L. Burattini, *La bilancia sincera [...]*, BNF, ms ital. 448, suppl. fr. 496.

17. '*Il [Burattini] fait une balance qu'il croit (personne ne l'ayant expliqué) que c'est celle d'Archimede. Il advoue que le dessein en est pris d'une assez imparfaitte de Galilée...'.* Letter from Pierre des Noyers to Father Marin Mersenne dated 29 February 1648, reproduced in Favaro, 'Intorno', p. 73.

18. 'I believe that he [Roberval] will have made you see the small tract of the Balance of Sir Burattin' ('*Je croy qu'il [Roberval] vous aura faict voir le petit traitté de la Balance de Mons.r Burattin*') – letter of Pierre des Noyers to father Marin Mersenne, reproduced in Favaro, 'Intorno', p. 74.

19. T.-L. Burattini, *Il volare non è impossibile come fin hora universalmente è stato creduto*, BNF, mss 11 195 of the Fonds Latins, f. 55–61.

20. See the caption to Fig. 1 for a short paraphrase of the legend as transcribed by K. Targosz, ' "Le dragon volant" de Tito Livio Burattini', *Annali dell'Istituto e Museo di Storia della Scienza di Firenze*, II (1977), p. 78.

its time at the Polish court but also among French scholars; in particular Mersenne was very interested in this work. Des Noyers described to him a small model of the dragon made by Burattini; it was four or five feet long, and its structure was made of whale bones.[21] Burattini wished to come to France to learn the opinion of the French scientists on his machine; he had undertaken to build one in spare parts to bring them and to have the advice of Pascal and Roberval, among others.[22] Burattini had a dimensioned drawing of his machine sent to Pascal, now preserved in the Archives of the French *Académie des Sciences.*[23] This document was sent to France through the intermediation of des Noyers,[24] which enabled Burattini to come into contact with several of the French scholars with whom he corresponded regularly.

It seems that Burattini abandoned his project before coming to France in 1650, as suggested by des Noyers in a letter addressed to Roberval dated 5 May 1649: 'If the dragon of Sir Buratin had been made, we would have gone to see you but it is for another time'.[25] The technical analysis by Jules Duhem shows however that, even if Burattini's enterprise was doomed to fail, he successfully optimized his concept of a flying machine with the separation of propulsive and lifting mechanisms, and thanks to this, was the first to obtain positive results, although not totally conclusive.[26]

Burattini also worked on the construction of a calculating machine inspired by Pascal's adding machine. Several copies of this machine had been imported into Poland very early on, one brought by the queen herself, two others ordered by des Noyers when he came to Warsaw and which arrived at the beginning of 1647.[27] Other machines seem to have been ordered afterwards, as shown by a letter from Roberval to des Noyers: 'I will see to it that you can have the Paschal as soon as possible'.[28] Burattini thus had the opportunity to observe these machines at a very early stage on his arrival in Poland. In 1658, he made a version that 'could be carried in the pocket' (*se porte dans la poche*,[29] as stated by des Noyers) and which he gave to Ferdinand de' Medici as attested by two letters from the mathematician Giovanni Alfonso Borelli in which he mentions an 'instrument or small box for numbers' (*istrumento o cassettina numeraria*). This machine was later mentioned in the inventories of the Medici's possessions, notably that of 1660, where it is described as follows:

> N. 585 in 1659 a brass instrument for calculation with 8 wheels, 3/4 long and 1/5 wide presented to His Serene Highness [Ferdinand de' Medici] by Tito Livio Burattini on 22 June.[30]

21. Letter from Pierre des Noyers to Father Marin Mersenne, reproduced in Favaro, 'Intorno', p. 73.

22. Targosz, ' "Le dragon volant" ', pp. 80–81.

23. R. Taton, 'Nouveau document sur le "dragon volant" de Burattini', *Annali dell'Istituto e Museo di Storia della Scienza di Firenze*, VII–2 (1982), pp. 161–168.

24. We have compared the legends of this diagram with the letters of des Noyers and confirm that it is indeed his handwriting.

25. '*Si le dragon de Monsr Buratin eust été fait nous vous fussions aller voire mais c'est pour une autre fois.*' Meyer, *Dei ex Machinis*.

26. J. Duhem, *Histoire des idées aéronautiques avant Montgolfier* (Paris: Fernand Sorlot, 1943), pp. 161–163.

27. Targosz, *La Cour savante*, p. 164.

28. '*Je fais en sorte que vous puissiez avoir au plus vite le Paschal*'. Letter from Gilles Personne de Roberval to Pierre des Noyers dated 28 June 1647, quoted by C. Grell, 'Pierre des Noyers : science et diplomatie à la cour de Pologne', in R. Maber (ed.), *La France et l'Europe du Nord au XVIIe siècle : de l'Irlande à la Russie – XIIe colloque du Centre International de Rencontres sur le XVIIe siècle* (Tübingen: Narr Francke Attempto, 2017), p. 73.

29. The term 'pocket' (*poche* in French) is not to be taken in its present sense but rather refers to a bag, see for example the definition of the dictionary of the French Academy of 1694: *POCKET. s. f. Bag of leather, canvas, cloth, silk, &c. attached by inside to a top of shoe, to a justaucorps, to a skirt, &c.* (https://dvlf.uchicago.edu/mot/poche)

This machine had approximately the same dimensions as a pascaline but must have been much lighter and therefore presumably very thin; it has thus been suggested that its mechanism must have been similar to Morland's adding machines.

The Galileo Museum in Florence holds a calculating machine that was once thought to be the one by Burattini but which does not match the description in the Medici inventories.[31]

Burattini was also known for the manufacture of large glass lenses for astronomical telescopes. He had begun to take an interest in this subject as early as 1648 but it was not until 1665 that he sent to Paris a sketch of an astronomical telescope and a machine for cutting the lenses of his own design. His lenses were recognised as being of very good quality; he later sent some to Florence, notably to Prince Leopold de' Medici.[32] Hevelius also insisted on ordering glasses from him.[33] It should also be noted that Burattini was the first to observe the spots on Venus and thus contributed not only to the development of techniques for astronomy but also to the increase of knowledge in this field.

Burattini is known to have made other technical achievements for which there is no comprehensive literature. It seems that he also worked on the design of a microscope and made a 'little one-wheeled car' pulled by one or two horses.[34]

The idea of the pendulum as a common thread

In addition to his interest in technical fields, Burattini took a close interest in the various scientific theories of his time and acted as an indirect informant to French scholars through des Noyers and Boulliau.[35] Thus, like other scientists at the same time, he tried to define a measure known as universal in the sense that it could be common to many peoples and countries. According to what he explained himself, this idea was inspired by Pudłowski to whom he had just presented his hydrostatic balance, explaining that he had found the proportion between the sphere and the cube by its means. Pudłowski had told him in rather formal terms: 'You are very close to finding something that the whole world has been looking for, that is to say the weight, the universal measure.'[36] It was also Pudłowski who would have suggested the use of Galileo's pendulum as the standard for Burattini's universal measure.

This idea occupied Burattini for decades. After his initial reflections with Pudłowski, he continued his research in Poland as testified by des Noyers in a letter addressed to Mersenne in which he discussed the treatise on the balance:

> He [Burattini] is now working on the second part [of the treatise on the balance], in order to reduce on it both the ancient weights and measures, and the means of preserving them in perpetuity, in a way that is easy for those who cannot read or write, and consequently are ignorant of arithmetic.[37]

30. '*N.585 in data 1659 uno strumento di ottone per fare abaco che ha otto ruote, lungo 3/4 largo 1/5 a S.A: serenissima donato da Tito Livio Burattini il 22 giugno*'. S. Hénin, 'Early Italian Computing Machines and Their Inventors', in A. Tatnall, *Reflections on the History of Computing: Preserving Memories and Sharing Stories* (Berlin: Springer, 2012), p. 211.

31. Hénin, 'Early Italian Computing Machines', pp. 211–212.

32. Targosz, *La Cour savante*, p. 152.

33. Grell and Mallet, *Correspondance de Johannes Hevelius*, p. 34.

34. Meyer, *Dei ex Machinis*, p. 96.

35. Grell and Mallet, *Correspondance de Johannes Hevelius*, p. 34.

36. '*Voi fiete arrivato molto vicino a trouvar una cosa tento riccercata da tutto'l Mondo cioè il peso la misura universale*.' Burattini, *Misura universale*, *Proemio.*

37. '*Il [Burattini] travaille maintenant a la seconde partie [du traité de la balance], pour reduire sur icelle tant les antiens poids que mesures de l'antiquité, et le moyen de les conserver a perpetuité, avec une manière facille pour ceux qui ne savent ny lire ni escrire, et par consequent qui sont ignorant de l'arithmétique.*' Letter from Pierre des Noyers to Father Marin Mersenne dated 21 May 1648, reproduced in Favaro, 'Intorno', p. 74.

Unfortunately, his various busy jobs prevented him from giving his full attention to this work until the 1670s, and it was not until 1672 that he wrote to Boulliau that he had 'almost completed [his] Treatise of the universal Measure and weight, which [he] hopes will be well received because its ease and convenience will make it agreeable to all'.[38] He named his standard of measurement the *Metro*, or *Metro Cattolico*, anticipating by more than a century the use of the word 'mètre' in the eponymous unit introduced after the French Revolution.

Burattini chose in practice to base his measure on the length of a pendulum beating the second, i.e. about 994mm, from which he could deduce a standard mass calculated as the mass of a cube of water whose side measures one-sixteenth of the standard length.

Burattini's treatise may not have been very successful because of its late publication. Indeed, although the idea of a universal measure came to him very early, Burattini was far from the only one to think of using the seconds pendulum as a measuring scale. The French astronomer Jean Picard as well as Mersenne, Christopher Wren, Huygens and a few others thought of it in the same period.[39] Furthermore, Jean Richer observed in 1672–73 that the period of a pendulum depends on gravitation and therefore on latitude, which greatly reduces the potential of the pendulum as a 'universal measure'.[40]

Anyway, Burattini's work is one of the earliest attempts to define a universal system of measurement and it will be seen later that this work had a direct influence on at least one, if not more of the clocks he built, which we will now present.

The water clock of the Grand Duke

The first mention of a clock that Burattini helped to make is by Pierre des Noyers. This clock is technically interesting because it seems to have been equipped with a pendulum at a very early date, and historically significant because it was made under the aegis of the Grand Duke, Ferdinand de' Medici.

The description given by Pierre des Noyers
In a letter to Ismaël Boulliau in which he explained that Burattini had just returned from Florence, des Noyers wrote:

> The Grand Duke [Ferdinand de' Medici] is working on a clock that will wind itself by means of water, and which is composed only of a very long weight, whose equal vibrations will move a small hand every minute, and it will be so accurate that in one year it will not vary by one minute, as they claim. The aforementioned Mr. Boratin has found a way to make this machine wind itself by means of water, and it is claimed that this clock will go on for a hundred years without needing to be corrected, that is to say, always assuming that nothing spoils it.[41]

The description given by des Noyers is rather obscure. The French word 'languette' certainly refers to a hand as suggested by the first edition of the dictionary of the French Academy of 1694.[42] This hand jumps 'every minute', the word 'minute' being understood here as a brief interval of time,[43] and not as the sixtieth part of an hour. In fact, it seems quite likely that the hand in question was

38. '*Ho quasi finito il mio Trattato della Misura e peso universale, che spero sarà ben veduto, perché la sua facilità e la sua comodità lo renderà grato a tutti*.' Meyer, *Dei ex Machinis*, p. 97.

39. Favaro, 'Intorno', pp. 36–44.

40. Meyer, *Dei ex Machinis*, p. 97.

41. '*Le grand-duc [Ferdinand de Médicis] fait travailler à une horloge qui se remontera soi-même par le moyen de l'eau, et qui n'est composée que d'un fort grand poids, dont les vibrations égales feront mouvoir une petite languette à toutes les minutes, et elle sera si juste, qu'en une année elle ne variera pas d'une minute, à ce qu'ils prétendent. Ledit sieur Boratin a trouvé le moyen pour faire que cette machine se remonte soi-même par le moyen de l'eau, et on prétend que cette horloge ira cent ans sans qu'il faille rien y corriger, c'est-à-dire toujours si rien ne s'y gâte*.' *LPDN*, letter CXXXIV dated 26 August 1657, pp. 342–43.

42. 'One also calls, *Languette*, This small piece of iron of a scale which is used to mark the balance, when it is with lead. *The* languette *of a scale*' (https://dvlf.uchicago.edu/mot/languette). The fourth edition of 1762 adds: '...& which others call *Aiguille*'.

indicating seconds, which would be consistent with the claimed accuracy of the clock and would thus have made it possible to check easily its accuracy.

On the other hand, it seems highly probable that this water clock was equipped with a pendulum. Des Noyers speaks of a 'very long weight' (*un fort long poids*) and 'equal vibrations' (*vibrations égales*), thus a long and isochronous oscillator which corresponds perfectly to the description of a pendulum. Des Noyers probably did not use this term because he had not yet been informed at the time of the application of the pendulum to clocks; we noticed that he does not use it either in his *Nativité d'Amarille*, when he uses 'a ball of lead [hung] on a brass wire' (*une boule de plom [pendue] a un fil de laiton*) to determine the time of the birth of the daughter of Louise-Marie, Queen of Poland.[44] The word 'pendulum' is also absent from certain works of the time that describe its use, notably the one attributed to Galileo.[45] On the other hand, after having been informed by Boulliau of Huygens's application of the pendulum to clocks, des Noyers would use the terms 'pendule' or 'pendulum' in several of his letters.[46]

Boulliau informed Huygens of the construction of the Grand Duke's clock in December 1657:

> I beg you to tell Mister Christian Hugens, that Mister the Grand Duke, is having a clock built, which should have the same effect as his own and should always measure the time equally. And that without winding it by hand, it will wind itself by means of water.[47]

Curious to know more, Huygens replied to Boulliau on 26 December:

> Mister Jannot recently showed me what you had written to him about the clock on which Mister the Great Duc was working, which should, as far as the effect is concerned, resemble mine. If you have since been told of any other particularities, I will be most obliged if you would inform me of them, so that I may know whether they also use the pendulum.[48]

It is in this same letter that Huygens explained that just one year ago he made the first model of his pendulum clock.

Boulliau replied that he would do his utmost to find out whether the Grand Duke's clock was equipped with a pendulum,[49] but in fact he seems never to have addressed this request to Pierre des Noyers, as it does not appear anywhere in their correspondence.

43. See the definition in the dictionary of the French Academy of 1694: 'It is often taken in conversation for a small space of time which is not precisely determined. *It is only a minute since he left. I will come back to you in a minute* (https://dvlf.uchicago.edu/mot/minute). See also Robert Moray's letter to Huygens dated 23 December 1661: '...a pendulum of the length it takes, to measure one minute second exactly, by each vibration...' ('*...un pendule de la longueur qu'il faut, pour mesurer une minute seconde exactement, par chaque vibration...*'), in *Œuvres complètes de Christiaan Huygens* (The Hague: Martinus Nijhoff, 1888–1950), hereafter *OC*, vol. III, letter 442, p. 427.

44. P. des Noyers, *Nativité d'Amarille*, Archives of the Condé Museum at Chantilly, ms 424, pp. 254–55, mistakenly numbered 154 and 155.

45. G. Galilei (attr.), *L'usage du quadran ou de l'horloge physique universel* (Paris: Pierre Rocolet, 1639).

46. See for example his letter to Boulliau dated 1 December 1657: 'We have already written to Holland to have the clock or pendulum of Christian'('*Nous avons déjà écrit en Hollande pour avoir l'horloge ou pendulum de Christian*'), LPDN, letter CXXXI, p.360.

47. '*Je vous prie de dire a Monsieur Christian Hugens, que Monsieur le grand Duc, faict travailler a une horologe, qui doibt faire le mesme effect que la sienne et mesurer toujours le temps egalement. Et que sans la remonter a la main, elle se remontera d'elle mesme par le moyen de l'eau.*' *OC*, vol. II, letter 442, p. 108.

48. '*Monsieur Jannot me monstra dernierement ce que vous luy aviez escrit touchant l'horologe à la quelle Monsieur le grand Duc faisoit travailler, qui devoit, quant à l'effect, ressembler à la mienne. Si depuis l'on vous a mandè d'autres particularitez, vous m'obligerez fort de me les apprendre, afin que je puisse scavoir s'ils se servent aussi du pendulum.*' *OC*, vol. II, letter 443, p. 109.

49. *OC*, vol. II, letter 448, p. 117.

Anteriority and posterity of the hydraulic winding system

Water-powered clocks existed long before the model built for the Grand Duke. In a recently published paper, Hwang, Yan and Lin describe the early development of this type of water-powered mechanical clock from antiquity to the fifteenth century.[50] The mechanisms that drive these clocks are generally quite simple and regulated by the flow of water, in one way or another, notably by the use of paddle wheels or buckets. Water plays a double role of driving energy and physical regulator.

After the application of the pendulum to clocks, some inventors tried to use water to maintain the oscillations of this new oscillator, as proposed by Perrault to Huygens in 1669.[51] Other clocks in which water plays only the role of driving energy have been built afterwards, with more or less success.[52]

All these mechanisms differ significantly from the one built for the Grand Duke where water remains outside the main mechanism, which it only serves to wind and thus plays only an indirect role. It is very likely that other engineers of the time designed clocks with hydraulic winding; Jean de Hautefeuille even proposed in 1678 a model capable of winding itself by the dilation of pine boards with the daily variations of temperature, which can be considered to some extent as the ancestor of the Atmos clock.[53]

It is possible that Burattini got the idea for the hydraulic system used to wind the Grand Duke's clock after seeing a machine that had been presented to him a year earlier, as des Noyers reported to Boulliau on 30 March 1656:

> A certain Mister Paulo del Buono, mathematician to the Grand Duke, is in Vienna with the emperor, who leases all the mines of the empire to him. He built a machine that Mr. Buratini saw, with which he can raise water over a distance of two or three Italian miles, and five or six men, without much effort, can raise about sixty thousand almuds in one day.[54]

Paolo del Buono was an engineer, a member of the *Accademia del Cimento* and according to Targioni-Tozzetti a disciple of Galileo.[55] He was a close associate of Burattini,[56] and was in charge of the management of mining and monetary workshops in Poland until his death in 1659.

Later, Burattini had another hydraulic machine built to supply water to the gardens of Andrzej Morsztyn's palace, as he himself explained to Boulliau in a letter dated 7 October 1672:

> The grand-treasurer of the kingdom, Mr. Morstin, is now building a magnificent palace here in Warsaw, with a garden decorated with very rare plants, but which lacks water. I amused myself by making a small model of a hydraulic machine to raise the water to a height of twenty-five to thirty ells[57] with the help of the wind. His Excellency, having

50. Z.-H. Hwang, H.-S. Yan and T.-Y. Lin, 'Historical development of water-powered mechanical clocks', *Mechanical Sciences*, 12 (2021), 203–219.

51. C. Aked, 'Perrault's hydraulic clock', *Antiquarian Horology* (June 1992), 161–168.

52. A. Mills, 'Water-driven clocks', *Antiquarian Horology* (June 1995), 136–145.

53. J. de Hautefeuille, *Pendule perpétuelle avec un nouveau balancier ; et la manière d'élever l'eau par le moyen de la poudre à canon, et autres inventions, contenuës dans une lettre de monsieur de Hautefeuille, écrite à un de ses amis*, 1678.

54. '*Un certain sieur Paulo del Buono, matematico del granduca, est à Vienne auprès de l'empereur, qui lui afferme toutes les minières de l'empire. Il a composé une machine que M. Buratini a vue, avec laquelle il peut élever l'eau à deux ou trois milles d'Italie, et cinq ou six hommes, sans beaucoup de fatigues, en peuvent épuiser environ soixante mille muids en un jour.*' *LPDN*, letter XLI, p. 125.

55. G. Targioni-Tozzetti, *Notizie degli grandi aggrandimenti delle scienze fisiche accudati in Toscana nel corso degli anni LX del Secolo XVII* (Florence: 1780), I, pp. 182–183.

56. Grell and Mallet, *Correspondance de Johannes Hevelius*, p. 29.

57. A *braccia* measured around 548mm in Florence at that time, so the small model was capable of raising water to a height of some fifteen to twenty meters.

seen this model, asked me to have it made in large size. It is a covered machine, enclosed in a tower, and which turns always in the same direction, wherever the wind blows from: because the weathervane is the regulator of the machine. There are no pumps at all: the water is raised by buckets, because pumps are easily disturbed, and buckets last for several years; and if some buckets are out of action, this does not affect the others. A very moderate wind is enough to raise four or five thousand barrels of water to the top of the tower in 24 hours: the excess water falls into the well. This machine does not require the assistance of anyone, because it does all the necessary operations itself, which makes it highly valued.[58]

The pocket pendulum timepiece

Although it is not certain that Burattini himself was at the origin of the application of the pendulum to Ferdinand de' Medici's clock insofar as his name is only associated with the winding system, it can be deduced that he was already aware, as early as August 1657, of the application of the pendulum to clocks, in one form or another. His training with Pudłowski certainly made him aware of the importance of this invention very early on, which he later tried to apply in various forms to at least three other experimental clocks: a 'pocket clock' and a seconds regulator, both described by Pierre des Noyers, and a wall clock with weights running for fifteen days.

In the meantime, Burattini had a clock by Coster sent to Ferdinand de' Medici on 27 September 1657, barely a month after the letter from des Noyers quoted above. This clock is described in an inventory of the Medici family's possessions written in 1690.[59] We can therefore suggest that Burattini was already aware of the application of the pendulum to clocks before participating in the construction of the Grand Duke's water clock, and that he may even have been the instigator of the use of the pendulum in this clock.

The description given by Pierre des Noyers
The first of the three other clocks designed by Burattini is first mentioned by des Noyers in a letter addressed to Boulliau dated 3 January 1660:

> Mr. Buratin tells me that he has added to Huygens's clock and that he is having one made that will fit in the pocket without stopping, he is quite inventive. We will see what he does, he has reformed the instrument of Mister Paschal and has made one that produces all the same effects, but with more ease and reliability and can be carried in the pocket.[60]

The word 'added' (*adjouté* in French) should probably be understood as an addition, an improvement: Burattini would have added [features, improvements] to Huygens's clock.

Here we find mention of the calculating machine designed by Burattini which is quite

58. '*Il Sigr. Grand Thesoriere del regno Morstin fa fabricare qui in Varsavia un bellisimo palazzo, et appresso a questo ha un giardino con piante molto rare, ma non ha acqua. Io per mio passatempo ho fatto un modeletto d'una machina hydraulitica per solevare l'acqua a forza di vento, vinti cinque in trenta braccia, et havendola veduta S. E. mi ha pregato, che gli la facci fare in grande come ho fatto. Questa machine sta chiusa in una torre et ècoperta, et si volta sempre per un verso sia il vento o da settentrione, o da mezzo giorno, o da levante overo da ponente, perchè la girandola o sia banderolla è quella che regola tutta la machina. L'acqua non viene condotta alla sommità della torre con le Pompe ma con secchielli, perchè quelle facilmente si guastano, e questi durano molti anni, e se qualche d'uno si guasta, li altri no mancano di fare l'offitio loro. Con questa machina con pochissimo vento si conduce di sopra nel recetacolo nel tempo di 24 hore quattro in cinque milla botte d'acqua, e la superflua cade nel pozzo. Non occorre che niuno vi assisti, perchè da se fa tutte l'operationi necessarie e farsi, la qual cosa sopra tutte l'altre viene stimata.' Correspondance et papiers politiques et astronomiques d'Ismaël BOULLIAU (1605–1694)*, BNF, ms 13044, leaflet 252.

59. For an excerpt from this inventory and its translation, see B. Hordijk and R. Memel, 'Salomon Coster, the clockmaker of Christiaan Huygens. The production and development of the first pendulum clocks in the period 1657 – September 1658', *Antiquarian Horology* (September 2021), 323–344; pp. 331–333. A slightly different translation is proposed by Silvio Bedini in his book *The pulse of time: Galileo Galilei, the determination of longitude, and the pendulum clock* (Biblioteca di Nuncius, 1991), p. 97.

late as we know that this machine had been manufactured at least two years earlier.

Des Noyers mentioned Burattini's 'pocket clock' again on 12 September 1660, once its manufacture was completed:

> Mr. Buratin has sent the Grand Duke a Huygens clock, which he has reformed, it is carried in the pocket and is no bigger than an egg, and it does not stop, it is in a glass case and always remains upright like the cardan lamps.[61]

Other portable pendulum timepieces

Although it may seem rather unexpected, Burattini's pocket clock is not an isolated case. Several watches and clocks equipped with a pendulum are known, all built during the same period, between 1660 and the end of the seventeenth century. It seems that the watchmakers and scientists who built these timepieces were so enthusiastic about the increased precision brought by the pendulum that they decided to apply it to mechanisms intended to be carried. Huygens's first trials were partially unsuccessful as he noticed that the cycloidal cheeks needed to be continually and exactly bisected by the perpendicular.[62] He then suppressed these cheeks and introduced the OP gearing in the model presented in his *Horologium* that should have enhanced the portability of his clock. Huygens also pointed out to Chapelain in June 1658 that if he could bring to sea some clocks with longer pendulums, he would have no doubt that one would succeed in determining longitude:

> if one could take to sea the long as successfully as the small, that is the ones which have a 3-feet pendulum as successfully as those which have a 6-inches one, then I venture to say, that it is certain one would succeed.[63]

Other scholars of this period shared the same reasoning which may explain why the belief in the viability of the pendulum at sea lasted so long. We know today that this approach was vain insofar as the precision of the pendulum relies actually on the regularity of its oscillations which are easily disturbed by small transverse movements, and that it is unfortunately not possible to significantly counteract these disturbances even by using a suspension or a cardan joint (which can moreover in certain cases amplify them, as long as the timepiece enters in resonance with its excitation frequency).

These timepieces fall into two categories: clocks intended to travel at sea for the calculation of longitude, and some watches that are more objects of curiosity.

To start with the first, the oldest 'hanging' pendulum clocks made after Burattini's are probably those used by Alexander Bruce for trials at sea, at least three years before Huygens designed and had made his own pendulum sea clocks. A synthesis of Huygens's work on this subject, in connection with Bruce's, and an analysis of the two known longitude clocks used by Bruce, are presented by Keith Piggott in the appendix 5 of his study related to Severijn Oosterwijck's royal

60. '*M. Buratin mescrit qu'il a adjouté à lhorloge d'Hugens et quil en fait faire une qui se portera dans la pochette sans s'arrêter, il est assez inventif. Nous verrons ce qu'il fera, il a reformé linstrument de Monsr Paschal et en a fait un qui en produit tous les mêmes effets, et avec plus de facilité et de sureté et se porte dans la poche.*' P. des Noyers, *Lettres de Des Noyers, secrétaire de la reine de Pologne à Ismaël Boulliau (t. I) – 1660–1665*, Diplomatic Archives of the Ministry of Europe and Foreign Affairs, 102CP/014, hereafter *LDNB*, letter dated 3 January 1660. We should point out that the transcription of Pierre des Noyers's letters presented difficulties. They are accessible only on microfilm, and contain gaps which we have filled in with what we believe are the most plausible words. The low contrast and the transparency of the ink made deciphering more difficult. Our transcriptions have been checked by two other readers accustomed to deciphering old handwriting and who confirm the versions proposed here. The English translations provided are almost literal.

61. '*M. Buratin a envoyé au grand duc une horloge d'Hugens, qu'il a reformee, elle se porte dans la pochette et n'est pas plus grosse qu'un oeuf, et ne sareste point elle est dans une boette de verre et demeure tousiours droite comme les lampes de cardan.*' *LDNB*, letter dated 12 September 1660.

62. '*la moindre inclination alterois la longueur du pendule*', *OC*, vol. II, p. 271.

63. '*si l'on en pouvoit porter par mer des grandes aussi bien que des petites, c'est a dire celles qui ont un pendulum de 3 pieds aussi bien que celles qui l'ont de 6 pouces, il est certain, que l'on en viendroit à bout*', *OC*, vol. II, p. 181.

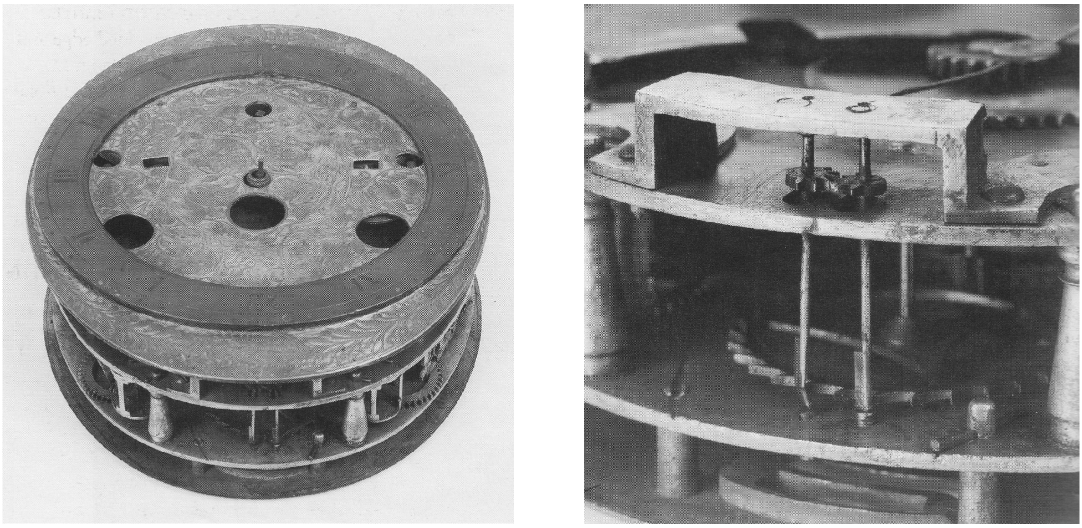

Fig. 2. Marine timekeeper with coupled quarter-second pendulums attributed to Kochański. Phillips London auction catalogue, *Clocks and Watches including Scientific Instruments*, 23 September 1997, lot 354 © Phillips London.

clock.[64] Synthetic elements can also be found in Huygens's *Œuvres Complètes*.[65] We will not dwell more on these clocks which have already been widely studied in the past.

Adam Kochański, a Polish Jesuit mathematician who worked for King John III Sobieski of Poland, also worked on the construction of a pendulum clock for determining longitude. This timekeeper had two quarter-second pendulums suspended with steel springs.[66] One can assume that the two pendulums were coupled, perhaps in the manner of Bürgi's cross-beat escapement, in anticipation of the system used later by John Harrison and which had already been put into practice by other scholars, notably Robert Hooke and Huygens.[67] Like Huygens, Kochański thought that longer pendulums could improve the accuracy of the clock at sea: 'certainly even with longer pendula suspended from suitable springs, one should not doubt successful outcome.'[68] Even if Kochański does not give a detailed description of his clock, a timepiece sold by Phillips auction house in September 1997, now in a private collection, seems to follow all the features of Kochański's marine timekeeper. This clock, illustrated in Fig. 2, with the photos taken from the auction catalogue,[69] has two coupled quarter-second pendulums and was apparently designed to be used at sea as it has a 4-minute dial, most probably for longitude measurement (1 minute is equal to 1 degree of longitude). It also has three trains with quarter-striking. There are conventional dials on one side and sliding apertures with cursors on the other side where the 4-minute dial is located. Some other features (remnant parts of a possible

64. K. Piggott, *A Royal 'Haagse klok' – Appendix 5: Alexander Bruce's English and Dutch longitude sea-clocks rediscovered*. www.antique-horology.

65. *OC*, vol. XVII, pp. 155–189.

66. A. Kochański, 'Mensurae universales magnitudinum ac temporum', *Acta Eruditorum* (1687), pp. 259–266. This text was recently translated in English by H. Fukś, *Mensurae Universales Magnitudinum ac Temporum by Adam Adamandy Kochański – Latin text with annotated English translation*, 2021.

67. B. Roobaert, *Résonance et sympathie IV – Deux régulateurs : pas nécessairement une résonance* (2022), pp. 3–4.

68. *'verum & in longioribus pendulis e convenienti elatere pendentibus, de felici successu dubitare non licet'*. Fukś, *Mensurae Universales*, p. 9.

69. *Clocks and Watches including Scientific Instruments and Barometers*, catalogue of auction at Phillips, September 1997.

Fig. 3. Pendulum watch with a gimbal system by Mattheus Hallaÿcher, c. 1675–80. Courtesy of Sotheby's.

gimbal suspension, decorations of the clock...) suggest a strong connection with Kochański's work. The owner of the clock provided more photos and will have the clock restored, which may be the occasion for an article dedicated to this highly unusual timepiece.

To come back to 'hanging' clocks, the cardan joint, in its 'annular' or 'ball' version, has been applied later to all timepieces used at sea, equipped with balance wheels. There are a few curious pieces from the late seventeenth century, two of which can be seen in the Vehmeyer collection.[70]

In parallel to the marine pendulum clocks, pendulum *watches* were also produced by some German and French watchmakers in the fourth quarter of the seventeenth century. These productions are rather late when one remembers that the spiral spring had been applied to watches as early as 1675 by Huygens; using a miniature pendulum at that time, instead of the recently invented spiral, may seem curiously anachronistic. However, it seems that these timepieces were not conceived with a scientific purpose but more as *curiosities* in the true sense of the word, i.e. atypical technological objects designed to arouse astonishment and admiration for the ingenuity shown by their makers.

We found five pendulum watches equipped with a pendulum and a cardan gimbal system, three of them similar to Burattini's and the

Fig. 4. Pendulum watch with a gimbal system, probably German. From von Bassermann-Jordan and von Bertele, *Montres, pendules et horloges*, p. 271, photographed in the Hessisches Landesmuseum, Kassel.

70. H. M. Vehmeyer, *Antieke uurwerken: een familieverzameling* (Utrecht: Hes, 1994), pp. 374–375.

Fig. 5. Pendulum watch with a gimbal system by Madelainy, c. 1685. From Chapiro, *La montre française*, p. 98, photographed in the former Time Museum Rockford.

other two also equipped with a pendulum but without a system to keep them in the optimal position.

The first of these watches (Fig. 3) was made by the watchmaker Mattheus Hallaÿcher and was recently sold by Sotheby's. Previously, it had been mentioned in the book of Guye and Michel[71] and sold by Antiquorum in 1999. The date of 1680, proposed by Guye and Michel and kept by Sotheby's, seems to us slightly late. A basin watch by the same watchmaker, very similar in style and proportions, was sold in August 2021 at Drouot by the auction house Vichy Enchères,[72] and dated before 1675 because it did not have a balance spring. Moreover, it is known that Hallaÿcher acquired the status of master watchmaker in 1672,[73] which constrains the lower dating of his pendulum watch, which is more likely to be around 1675.

This piece is composed of a rather classical mechanism with four notable features:

1. A short pendulum is used instead of the classical balance wheel. It oscillates in a plane perpendicular to that of the dial, which avoids the use of a contrate wheel to change the plane of rotation.
2. The movement is weighted by a mass added at the opposite to the dial, on the back of the mechanism.
3. The mechanism is suspended with a system of two articulated rings which allow to

71. S. Guye and H. Michel, *Mesure du temps et de l'espace* (Paris: Bibliothèque des Arts, 1970), p. 83.

72. https://www.gazette-drouot.com/article/le-luxe-dans-la-poche/26660.

73. J. Abeler, *Meister der Uhrmacherkunst* (Abeler, Wuppertal, 1977), p. 251.

Fig. 6. Pendulum watch by Martin Gerdts, c. 1680. From Chapiro, *La montre française*, p. 97, photographed in the Nationalmuseet, Copenhagen.

compensate the random movements of the watch case. In this way, the dial can remain parallel to the ground, whatever the orientation of the case.

4. The watch is enclosed in a spherical case that accommodates the internal gimballing of the mechanism.

The precision of this timepiece was certainly very poor: in spite of the gimbal system, the lightness of the pendulum must have made it particularly sensitive to external disturbances, in addition to being difficult to adjust because of its small size.

The watch shown in Fig. 4 is very similar to Hallaÿcher's in both style and structure. It probably dates from the same period.

A third French watch signed Madelainy, built on the same principle, can be seen in Fig. 5.[75] It has the same four features mentioned above but is later, around 1685, and has a slightly longer pendulum an unevenness (French: *méplat*) was cut in the counterweight to allow its passage. It was previously in the collection of the Rockford Time Museum,[76] and is now in the Patek Philippe Museum in Geneva.

Two other watches equipped with a pendulum are shown in Fig. 6[77] and Fig. 7[78], without a cardan joint to keep them straight. They are both by the German watchmaker Martin Gerdts. The pendulum is longer than in the watches mentioned earlier and oscillates between two thin springs which tend to bring

74. E. von Bassermann-Jordan and H. von Bertele, *Montres, horloges et pendules* (Paris: Presses Universitaires de France, 1964), p. 271.

75. A. Chapiro, *La montre française du XVIe siècle jusqu'à 1900* (Éditions de l'Amateur, 1991), pp. 98–99.

76. *Masterpieces from the Time Museum Part II*, catalogue of auction at Sotheby's, June 2002.

77. Chapiro, *La montre française*, p.97.

78. von Bassermann-Jordan and von Bertele, *Montres, horloges et pendules*, p. 270.

Fig. 7. Pendulum watch by Martin Gerdts, *c.* 1680. From von Bassermann-Jordan and von Bertele, *Montres, pendules et horloges*, p. 270, photographed in the Hessisches Landesmuseum, Kassel.

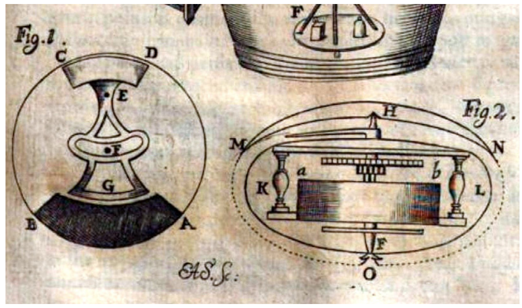

Fig. 8. Adam Kochanski's magnetic pendulum watch, 1685. *Acta Eruditorum* (1685), tab. X, Figs 1 and 2. Public domain.

it back to its equilibrium position (on the piece in Fig. 7, the left spring is broken; this last piece seems to be more recent than the first one because a system of screw adjustment of the springs has been added). Ironically, it is likely that these watches worked much better than the previous ones: if the pendulum was light enough, it must have been not much influenced by gravity compared to the restoring forces of the springs, and must then have behaved like a classical foliot equipped with a straight spring, as were some early timepieces, e.g. one signed by Thomas Penn presented in Chapiro's book.[79]

Finally, it seems interesting to us to mention a very curious pendulum watch, quite different from the previous ones in its working principle, whose mechanism is shown in Fig. 8. This watch was conceived by Adam Kochański who described it in the 1685 edition of *Acta Eruditorum*,[80] from which Fig. 8 is taken. This description was rediscovered by Baillie in 1948,[81] and was recently the subject of a short paragraph in Bedini's posthumous work on Giuseppe Campani.[82] Its inventor explains having conceived it in 1659. Its working principle is particularly ingenious and has acquired some posterity as it is found in a number of modern electric clocks.[83] The mechanism is that of a classical watch with a 'pendular' iron oscillator which is free to oscillate around the point E. The lower end of this oscillator is placed close to a magnet AB; the air gap formed by the gap between the oscillator and the magnet creates a restoring force which substitutes to gravity. Note that the mechanism is mounted between two pivots F and H, so as to keep the magnet AB always down. Kochański states that he showed such a watch to Ferdinand de' Medici in 1667.

Kochański's watch, like Burattini's (which 'always remains straight'), has its dial vertical. This is in fact the only apparent similarity that can be found between these two watches and which is not found on the models with gimbal suspension described above. However, it seems unlikely that Burattini could have been inspired by Kochański's design to build his own model, which he would also offer to the Grand Duke. Although his name does not appear

79. Chapiro, *La montre française*, p.36.

80. A. Kochański, 'Adami Adamandi e Soc. Jesu Kochański Sereniss. Polon. Regis Mathematici, Novum genus perpendiculi pro horologiis rotatis portabilibus. Vulgarium elatere vibrante instructorum nova disponitio & ex hac suprema perfectio', *Acta Eruditorum* (1685), pp. 428–433.

81. G. H. Baillie, 'Magnetic watch balance of 1659', *Horological Journal* (December 1948), p. 749.

82. S. Bedini, *Giuseppe Campani, "Inventor Romae", an Uncommon Genius* (ed. Cristiano Zanetti, Brill, 2021), pp. 106–107.

83. The present author is preparing an article on this mechanism as well as on other early attempts to apply magnetism to clockmaking.

anywhere in Burattini's correspondence, it is known that they had been friends as was reported by Kochański himself ('*T. Livius Burattini, amicus quondam meum*'[84]). However, Kochański was not introduced to the Polish king until 1678 and did not arrive at his court until 1680, barely a year before Burattini's death, and it seems that they only knew each other well during this short period, after which Kochański began to publish his research in the *Acta Eruditorum*.

A curiosity or a timekeeper for the longitude?
We have seen that portable pendulum timepieces fall into two categories: marine timekeepers and objects of curiosity. Even if it is quite clear that the watch offered by Burattini to the Grand Duke logically falls into the latter category, one can legitimately wonder if Burattini had not considered applying this concept to a regulator for the calculation of longitude. Indeed, considering the relationship he had with several scholars throughout Europe, it seems almost certain that he was familiar with the longitude problem, and given his perpetual quest for precision, he could well have decided to build a 'marine pendulum watch'. If such a piece did exist, there seems to be no trace of it today. Perhaps Burattini did try to build a sea clock, which he could have tested during his travels, but the poor performance of such a device would have made him abandon this project. This is of course only a hypothesis that we cannot support or refute with the elements we currently have.

The seconds regulator

A third clock by Burattini is mentioned by des Noyers to Boulliau and seems to be a precision regulator, undoubtedly built for scientific purposes, which bears a striking similarity to one of the clocks designed by Johannes Hevelius.

The description given by Pierre des Noyers
In the same letter of 12 September 1660 mentioned above, just after mentioning Burattini's pocket clock, des Noyers continued:

> ...he has since had another [clock] made, with the minutes and seconds, which has only two wheels, and which for this reason must be very accurate, this one is large to be attached in a room and has the perpendicular or pendulum very long, and goes with weights, it has been proved that they are more accurate than springs, as has proved Mr. Hevellius.[85]

Possible link with the work of Johannes Hevelius
To design this clock, it seems that Burattini was inspired by the work of one of his correspondents and friends, the astronomer Johannes Hevelius, who claimed to have conceived the application of the pendulum to clocks in parallel with Huygens. According to what he writes in his book *Machina Coelestis*, he would have started by adding a counter system to the end of a string in order to automatically count the oscillations of the pendulum and to visualize them, without however maintaining its movement.[86] Later, with the collaboration of a Swedish craftsman, Hevelius would have made two clocks with experimental pendulums, 'without foliot, without spring, without fusee accompanied by its cord or chain in spiral, but only with a pendulum, a weight and some cogwheels'; he presented the smaller of these two clocks to the king of Poland John Casimir, during the king's visit to his observatory on 29 December 1659.[87]

84. Kochański, 'Mensurae universales magnitudinum ac temporum'.

85. '*...il en a depuis fait faire une autre [horloge], avec les minutes et secondes, qui n'a que deux rouë, et qui par cette raison doit être dans la dernière justesse, celle cy est grande pour être atta[chée] dans une chambre et ha le perpendicule ou balancier fort long, et va avec des poids, on a esprouvé qu'ils sont plus justes que les resorts, cest M. Hevellius qui en a fait la preuve*.' *LDNB*, letter dated 12 September 1660.

86. J. Hevelius, *Machina Coelestis* (Danzig: Simon Reiniger, 1673), pp. 364–65.

87. '*absque tamen irrequieto, elatere, pyramide æquatoreà, chordà huic circumvolutâ vel catenulâ, solo videlicet pendulo, uno pondere, paucisque tantùm rotulis dentatis*.' Hevelius, *Machina Coelestis*, p. 366.

It is unfortunate that Hevelius gives only a brief description of his pendulum clocks, considering that they constitute one of the earliest experiments of the application of the pendulum oscillator to a clock mechanism. However, we have another description of the smaller of the two clocks (the one presented to the King of Poland), again by Pierre des Noyers. Indeed, in the same letter of 3 January 1660 that we quoted above, des Noyers told Boulliau about John Casimir's recent visit to Hevelius's observatory. Hevelius, wishing to impress the king of Poland, showed him his various instruments, among which was

> ...a clock that is an improved version of that of Christian Hugens, this one goes with weights, and the pendulum is much longer, although the clock is quite small. But as he wanted the minutes [and] seconds to be marked, the pendulum's going marks one, and the return another, so that 60. both goings and comings make one minute first, and this was necessary for perfection.[88]

The description of the clock given by des Noyers is consistent with that of Hevelius himself: the clock is indeed small and marks the seconds.

The meaning of the French word '*augmen[té]*' is rather obscure. It seems that this adjective refers to a notion of improvement: an 'augmented clock' could mean a clock that is perfected, improved, which is the English translation proposed above.

It may seem surprising that des Noyers should mention the use of weights and the length of the pendulum of the Hevelius model in comparison with Huygens's clocks when we know that the design revealed by Huygens in his *Horologium* had one of these two characteristics, and that clocks with a long pendulum had already been experimented by Huygens as early as 1657. It seems in fact that des Noyers was not aware of these clocks at the beginning of 1660 and had only seen one pendulum clock before, the one made by Coster and sent to Poland in May 1658:

> The Electress [of Brandenburg] has sent the Queen the clock of Christian Huygens; it has alarum and striking in an ebony frame; we shall see how it goes.[89]

Given the description of this clock, which was certainly a 'classical' Coster model, similar to the D5 and D8 models[90] with a spring and a short pendulum, des Noyers's comment is fully justified.

Hevelius points out that his clocks had four wheels for the smaller one and only two wheels for the larger one, like Burattini's. Is this a coincidence? Probably not, since Burattini corresponded with Hevelius and visited him several times; he could therefore have observed Hevelius's clocks early on and been inspired by them to design his own regulator.

Technical and historical justification of these clocks

Clocks with a reduced number of wheels (only one or two) existed long before those of Hevelius and Burattini. Silvio Bedini has described a clock of this type dating from the sixteenth century, perhaps inspired by a much older construction dating from the fourteenth century.[91] Regarding Hevelius, he

88. '*...un horloge augmen[té] de celuÿ de Christian Hugens, celuy cy va avec des poids, et le pendule en est beaucoup plus long, bien que lhorloge soit assez petit. Mais comme il a voulu que les Minutes [et] seconde y fussent marquées, l'all[ée] du pendulum en marque, et le retour unautre, de sorte que 60. tant allees que venuë font une minute premiere, et cela estait necessaire a la perfection*.' *LDNB*, letter dated 3 January 1660.

89. '*Mme l'électrice [de Brandebourg] a envoyé à la reine l'horloge de Christian Huygens; elle a réveil et sonnerie dans un cadre d'ébène; nous verrons comment elle ira*.' *LPDN*, letter CLIV dated 23 May 1658, p. 411.

90. This nomenclature was introduced in R. Plomp, *The earliest Dutch and French Pendulum clocks, 1657–1662* (December 2005, antique-horology.org). It is still used today by some authors, although the initial chronology of Plomp should probably be revised as suggested by Keith Piggott in his numerous studies on the first Coster clocks.

91. S. Bedini, 'One-wheeled clocks and the clocks with two or three wheels', *La Suisse horlogère et Revue internationale de l'horlogerie*, 4 (December 1962), pp. 23–34. This article was translated into French and published in the journal *Horlogerie Ancienne*, 40 (1996), pp. 25–36.

Fig. 9. Regulator attributed to Jost Bürgi, *c.* 1590. https://datenbank.museum-kassel.de/46943/. Courtesy of Hessen Kassel Heritage.

was probably inspired by the mechanisms of Jost Bürgi, whose cross-beat escapement ('*duplici libramento*') he mentions in his *Machina Coelestis*.[92] Bürgi was one of the first to build clocks with very large wheels ; one of them, made for Tycho Brahe, had 1200 teeth.[93] Among Bürgi's surviving clocks, one of his regulators has only two wheels (Fig. 9).[94] This architecture was adopted by several other clockmakers who used Bürgi's cross-beat escapement; as an example, it is found in a Danish clock dated 1642[95] and in a model attributed to Johannes Buschmann, preserved in the British Museum collections, which has only one escapement wheel of 300 teeth.[96]

Another common feature of the Burattini and Hevelius regulators is the indication of seconds and the presence of a seconds pendulum. This layout naturally emerged from the use of these clocks for astronomical observations with which these two men were familiar; this is also the reason why Tycho Brahe used such clocks with a seconds hand, and why Huygens would also have some made.

Possible reconstructions of the clocks

It seems interesting to us to propose a reconstruction of the two-wheel regulators of Burattini and Hevelius in order to compare the technical aspects that should differentiate them. Indeed, if we admit that Hevelius had his clocks made without knowing Huygens's models, as he explains in *Machina Coelestis*, he would not have integrated the technical features designed by Huygens (the fork, the endless rope...) that Burattini would have discovered on the Coster clock that he was to send to Italy, and probably by consulting *Horologium* of which Hevelius received a copy as soon as it was published in September 1658,[97] and of which another copy was sent to Florence by Boulliau in October of the same year.[98]

92. Hevelius, *Machina Coelestis*, p. 367.

93. T. Brahe, *Astronomiae Instauratae Mechanica* (Wandesburgi, 1598), p. 29.

94. See, for example, H. A. Lloyd, *Some outstanding clocks over seven hundred years – 1250–1950* (Glasgow: The University Press, 1958), pp. 61–69, and H. von Bertele, 'Precision timekeeping in the pre-Huygens era', *Horological Journal* (December 1953), 794–816; pp. 811–812.

95. H. von Bertele, 'Early Clocks in Denmark', *Horological Journal* (March 1955), pp.172–176.

96. https://www.britishmuseum.org/collection/object/H_1973-0202-1.

97. *OC*, vol. II, p. 209.

98. *OC*, vol. II, letter of Ismaël Boulliau to Christiaan Huygens dated 18 October 1658, p. 253.

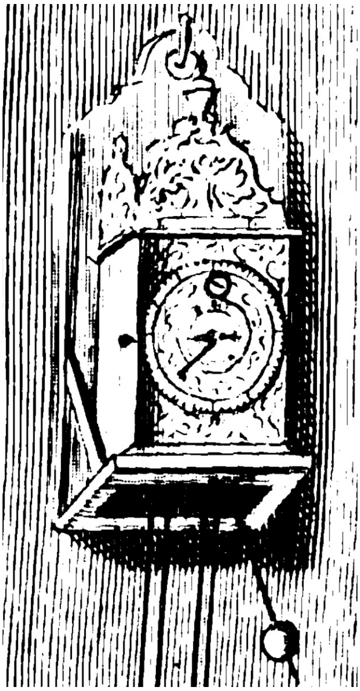

Fig. 10. Pendulum timepiece from Hevelius, *Machina Coelestis*, plate D.

Some extrapolated views of the regulators are shown in Fig. 11, drawn from the descriptions of des Noyers and Hevelius and following some hypotheses that will be justified in the following paragraphs.

The first step in the reconstruction was to figure out the probable layout of the going trains. For this purpose, we know that the clocks had only two wheels, that they indicated hours, minutes and seconds, and that they were equipped with a pendulum beating seconds. We deduce that the second hand was logically fixed on the escapement wheel arbor and the minute hand on the main driving wheel arbor. The hours were probably indicated by a hand concentric to the minute hand, driven by a classical motion work. It seems also logical that the escapement wheel was located above the driving wheel, as was customary at that time. Therefore the dial layout must have been similar to that of the Huygens clock shown in *Horologium Oscillatorium*,[99] with a seconds dial positioned above or inside the main dial. Besides, it must be noted that the pendulum clock shown on the top right of plate D in *Machina Coelestis* (reproduced in Fig. 10) has a small seconds dial at 12 o'clock and two concentric hands on a large central dial;[100] indeed, the central dial is composed of three concentric rings of which the inner two seem to have 12 graduations and the outer one 60, which may correspond to an indication of the hours and minutes by two concentric hands. Hence we decided to reproduce this dial as faithfully as possible in the top reconstruction of Fig. 11, although there is no evidence that this clock is actually one of those made for Hevelius, mentioned in his book.

One may also notice that a similar dial layout (although somewhat different) can be seen on the clocks of Tycho Brahe represented in an engraving dating from 1587,[101] as well as on the Treffler clock which may have been a 'copy' of the Coster clock sent by Burattini to Ferdinand de' Medici.[102]

Regarding the number of teeth, the escapement wheels necessarily had 30 teeth to be compatible with a seconds pendulum. With a ratio of 1:60 between this wheel and the driving wheel, one can assume that the latter had 300 or 360 teeth to mesh with an escapement wheel pinion of respectively five or six teeth, which was classical at the time. Wheels with 300 teeth can be found on the third Bürgi regulator , on the clock attributed to Buschmann in the British Museum and on the 'BX3i' regulator attributed to Bürgi;[104] a 360-tooth wheel is used on the Danish clock described by von Bertele.[105]

99. C. Huygens, *Horologium Oscillatorium* (Paris: F. Muguet, 1673), p. 4.

100. Hevelius, *Machina Coelestis*, plate D, pp. 114–115.

101. von Bertele, 'Precision timekeeping', p.794 and p.796.

102. K. Piggott, *A Royal 'Haagseklok', Appendix Three, Open-Research, Memo-Treffler: Johann Philipp Treffler's 1657/8 Pendulum Timepiece (DØcopy)*.

103. Lloyd, *Some outstanding clocks*, plate 72. There are 50 teeth on one sixth of the escapement wheel for a total of 300 teeth. Lloyd mentions the number of 360 teeth but seems to be in error (p. 64: 'the assumption is that the escape wheel has 360 teeth, although from the photograph is has not been possible actually to confirm this.').

On both clocks, a weight provided the driving force. It is likely that endless rope was installed on Burattini's regulator (he would have learned about it in Horologium), as des Noyers says that the clock worked 'with weights' (*avec des poids*). However, he uses this same formulation to describe the clock of Hevelius who spoke of one weight (*uno pondere*) in his *Machina Coelestis*. From then on, we can formulate three hypotheses:

– des Noyers used the plural in the general sense, without relating to the actual number of weights that equipped the clocks;
– Hevelius added endless rope to his clock, which did not have one initially;
– the second weight refers to the counterweight needed on pre-endless-rope clocks.

The second hypothesis seems to us the most probable insofar as the pendulum clock of plate D in *Machina Coelestis* has two weights (one heavy and one light) with two pulleys, which suggests the use of Huygens's endless rope; *a contrario*, the clock on its right, which does not have a pendulum, has four weights for two trains of gears but without pulleys, which is commonly found on lantern clocks of the same period.

The most difficult part of the mechanism to extrapolate is the escapement. It could not have been a traditional escapement with contrate and crown wheels because the escape wheel had to be in a vertical plane, parallel to that of the driving wheel, to indicate the seconds. There are therefore two possibilities:

1. The escapement wheel was a classic crown wheel and a fork was used to make the link between the verge and the pendulum rod to allow the change of the rotation plane.
2. The escapement wheel was a 'saw wheel', as in the Bürgi regulators, and an escapement similar to Bürgi's was used.

The first layout may correspond to the one found in *Horologium*, where a 'pirouette' escapement is used to convert the vertical rotation of the verge into an horizontal rotation of the pendulum (the OP system). Burattini, who was certainly aware of this layout, may have put it into practice in his own regulator. Another possibility was to use an escapement similar to the one that equipped the Scheveningen bell tower clock, converted in 1658 to a pendulum oscillator, which uses a kind of fork to link kinematically the verge to the pendulum,[106] an arrangement that was later applied to the Dutch 'Zaandam' clocks.[107]

The second layout, similar to the escapement of Bürgi, is, in our opinion, the one that may have been used by Hevelius. Indeed, it seems that he was aware of the high precision of Bürgi's clocks ('I was never able to find any clock, even one with a double balance, which completely avoided all irregularities'[108]), so he probably had one cross-beat clock in his possession. It is also known that Ahasuerus Fromanteel applied a cross-beat escapement to a pendulum clock about 1663 or 1664, followed by Joseph Knibb.[109] These escapements ante-dated the later variants known as 'Chevalier de Béthune' that we find from the eighteenth century onwards.[110]

We decided to illustrate these two escapement layouts by representing them

104. K. Piggott, *Ahasuerus Fromanteel's 1649 Cromwellian and Royal Astronomical Sun-Clock*, p. 32. This Bürgi clock appears to be presently in the Patek Philippe Museum, see P. Friess, *Treasures from the Patek Philippe Museum – The Emergence of the Watch* (teNeues Media GmbH & Co. KG, 2022), p. 31.

105. von Bertele, *Early Clocks in Denmark*, p. 175.

106. For a photograph of this escapement, see Hordijk and Memel, 'Salomon Coster, the clockmaker of Christiaan Huygens', p. 336. Another view is presented in A. J. Servaas van Rooijen, 'Het Slingeruurwerk van Christiaan Huygens', *Eigen Haard*, 1899, p. 107.

107. E. L. Edwardes, 'Old Dutch clocks', *Antiquarian Horology* (June 1973), 254–275.

108. Hevelius, *Machina Coelestis*, p. 363. The translation is from G. Baillie, 'Most important item of a horological bibliography', *Watch and Clock Maker*, 95 (February 1936), p. 433.

109. K. Piggott, *A Royal 'Haagse klok' – Appendix 7: the pendulum – aequations and tides*, p. 8 and p. 14

110. D. Cousin, 'The 'Chevalier de Béthune' escapement', *Antiquarian Horology*, (September 2021), 349–364.

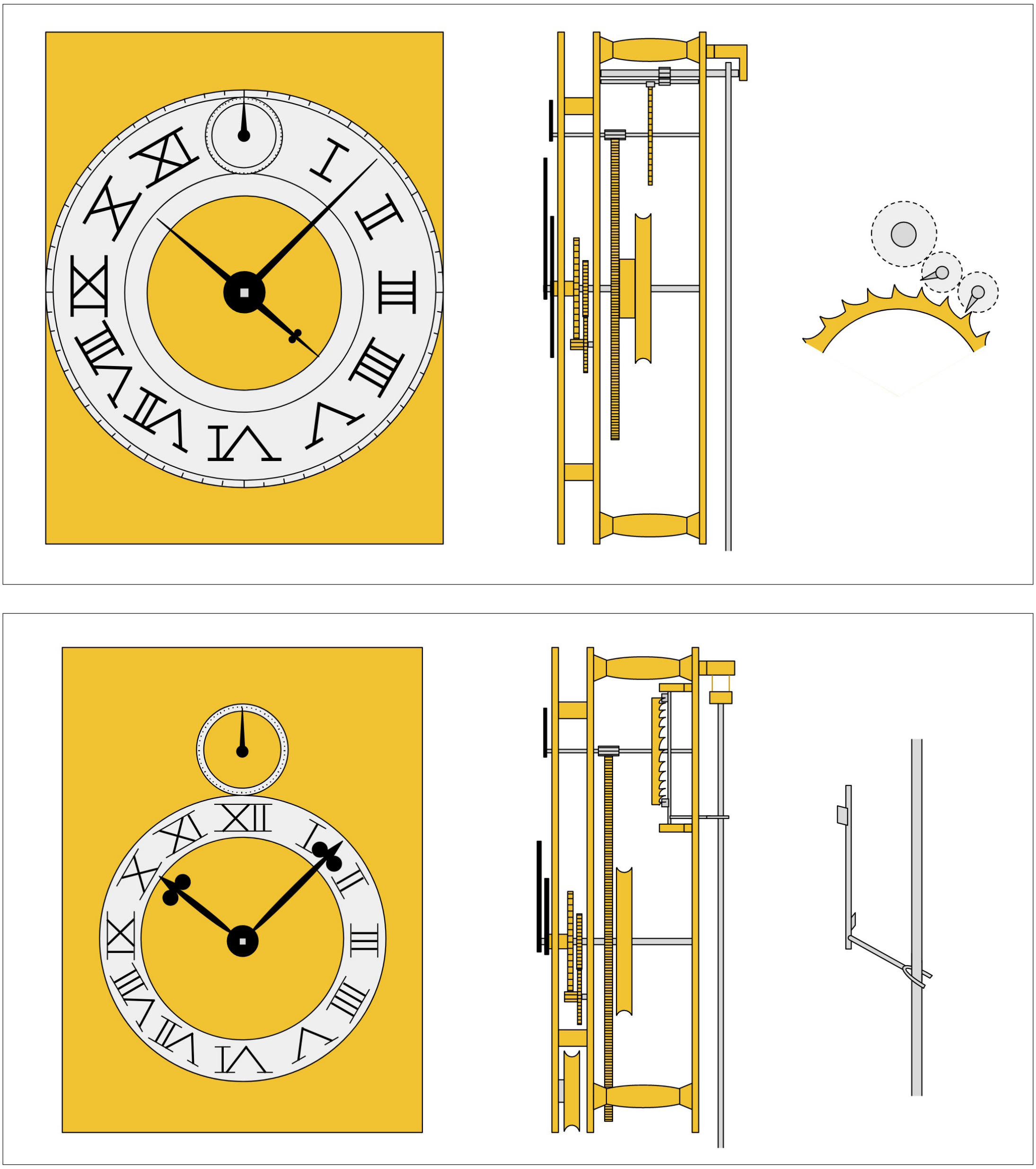

Fig. 11. Possible reconstructions of the clocks of Hevelius (top) and Burattini (bottom). © Augustin Gomand.

in Fig. 11, the first on Hevelius's clock, the second on that of Burattini. On the former we have drawn the pendulum rigidly fixed to an arbor rotating between two pivots, following Hevelius's description, a layout that he abandoned later to use a silk suspension which would have equipped Burattini's regulator. A final difference between the two mechanisms was introduced by the addition of an endless rope on Burattini's clock, as discussed above.

Through the reconstructions presented here, one can see that the clocks of Burattini and Hevelius must have been quite similar, constrained in their architecture by the use of a reduced gear train that beats the second which imposes a certain dial layout and certain numbers of teeth. The differences between these two regulators probably resided in technical details – the escapement, the suspension of the pendulum, the rope – which however had their importance for the precision of the timepieces and their practical use.

A later pendulum clock

Burattini's surviving correspondence and the few elements reported by des Noyers about him give us a brief overview of his work, which unfortunately lacks most of his technical achievements. It seems very likely that Burattini conceived other clocks of which no mentions or descriptions have reached us.

There are two letters sent by Burattini in 1667 and 1668 in which he mentions a last clock sent to Prince Leopold de' Medici. To our knowledge, these are the last mentions of a clock by Burattini, which he described as follows in a letter dated 9 February 1667:

> A few weeks ago I sent to Venice a clock made in my house, which works for two weeks without being wound more than once, and in that time the weight does not fall more than two ells. I have destined it for the Most Serene Grand Prince as a token of my humble obedience.[111]

In a second letter dated 23 May 1668, Burattini wrote:

> The clock Your Lordship received I sent to the Most Serene Great Prince last year; it runs for two weeks and measures only 2 3/4 ells from the ground, but the counterweight must be three times as heavy as the whole body of the clock including the key. Instead of a rope and chain, I used a brass or silver wire that was baked, that is, fired until it turned purple, and such a wire lasts four to five years without breaking. I know that it is not the most beautiful thing in the world, but as it is wound up once a fortnight, it works very well, but I dare to present it to His Serene Highness, as I beg Your Serene Highness to do on my behalf, when His Highness returns to Florence, who was expected here in Poland by many, but who has taken another route.[112]

Indeed, in 1668, John Casimir abdicated the Polish crown and retired to France as abbot of the abbey of Saint-Germain-des-Prés where he contributed to the development of the mechanical arts in this Mecca of Parisian clockmaking [113]

Using the correspondence with the *braccia* (ell) used in Florence, the distance from the floor to the top of the hanging clock would have been about 1.5 meters and the clock itself would have been about 40 centimeters high at most, probably less. Given these dimensions, it is possible that the clock had a seconds pendulum. It may be assumed that it was similar to the two-wheel regulator of 1660 but in the absence of further information, it is impossible to know more.

111. '*Alcune settimane sono mandai a Venezia un orologio col pendolo fatto fare qui in casa mia il quale cammina due settimane senza esser montano che una sol volta, et in questo tempo il contrapeso non scende che doi soli bracci. L'o destinato per il Ser.mo gran Principe in tributo del mio humillisimo obsequio.*' Copy of a letter of Burattini dated 9 February 1667, Archivio di Stato di Firenze, Mediceo del Principato, 4489, leaves 1301 v. – 1302 r.

112. '*L'orologgio, che V. S. Ill.ma ha ricevuto, io lo mandai al Ser.mo Gran Principe sino l'anno passato; camina doi settimane posto alto da terra solo doi braccia e tre quarti, ma il contrapeso deve esser tre volte più pesante di tutto il corpo del orologgio compresa la chiave. In vece di corda e di catena mi servo d'un filo d'ottone o d'argento cotto, cioè messo nel fuoco sin che prendi il colore di porpora, ed un tal filo dura quattro o cinqu'anni senza rompersi. So bene che non è la più bella cosa del mondo, ma perchè si tira su ogni doi settimane una volta, va giustissimamente, però ho ardito di presentarlo a S. A. Ser.ma come prego V. S. Ill.ma di far ciò in nome mio, quando S. A. sarà ritornato a Fiorenza, il quale era atteso qui in Polonia da molti, ma ha preso altro camino.*' Favaro, 'Intorno', p. 120. The original letter is in the National Library of Florence, mss. Galileiani. Div. V. Cimento. 19, car. 176–179.

113. J.-D. Augarde, *Les ouvriers du temps* (Geneva: Antiquorum éditions, 1996).

Conclusion

In this article, we have described four timepieces which the Italian-Polish engineer Tito Livio Burattini conceived and commissioned or built himself. These designs are among the few documented examples of early experiments in the application of the pendulum to clocks, inspired by the work of Huygens. Moreover, they also inform us about Burattini's scientific approach and the logic he followed as an engineer to design these innovative constructions.

It is interesting to note several similarities between Burattini's different horological works, and between these mechanisms and his other constructions.

First of all, one can notice that Burattini 'liked to perfect the discoveries already made' (*aimait à perfectionner les découvertes déjà faites*) as Karolina Targosz has pointed out.[114] It appears indeed that his various machines, whether they are his pendulum clocks, his hydraulic machine, his hydrostatic balance, his calculating machine or his 'flying dragon', are not inventions in the strict sense of the word but only *innovations*, *improvements* of existing machines, albeit all recently invented. Burattini's approach consisted above all in thinking of these machines as concepts that had to be brought to perfection and to an ultimate level of precision, a state of mind that he shared with Pierre des Noyers who was also very demanding with regard to the quality and precision of the instruments he used.[115] This daily quest for excellence was in fact the prerogative of many scholars of this period, linked to the social context and to the significant development of scientific rigor, as well as to the birth of precision astronomy in the seventeenth century.[116]

Burattini's search for perfection goes with a preference for simplicity: the Grand Duke's water clock 'is composed only of a very large weight' (*n'est composée que d'un fort grand poids*) and Burattini's regulator had only two wheels. He was undoubtedly inspired by his contemporaries, including Hevelius, and by inventors who preceded him, such as Jost Bürgi, who had noticed that any moving part necessarily induces friction and consequently a disturbance. For this reason they sought to simplify mechanisms to the extreme in order to keep only the indispensable parts, well before 'modern' watchmakers such as Bréguet who believed in an aesthetic of simplicity.

A corollary to the simplicity sought by Burattini is the practical aspect of his creations: his hydrostatic balance allowed 'to realize one hundred operations where only one is realized with that of Galileo' (*faccio piu presto cente operazioni, di quello se ne puo far una con quella del signor Galileo*[117]) and his calculating machine is used with 'more ease and reliability' (*plus de facilité et de sureté*) than Pascal's (as stated by des Noyers). Burattini actually conceived his instruments not only as a scientist but above all as an *engineer*, aware of their daily practical use; this quality of mind distinguishes him from some scholars of the period who are known today for having conceived numerous devices technically perfect on paper but which proved to be unusable from a practical point of view.[118]

One can think that it is this quest for sobriety and convenience that led Burattini to conceive his universal scale of measures, a

114. Targosz, *La Cour savante*, p. 164.

115. D. Mallet, 'Pierre des Noyers, a Scholar and Scientific Intermediary at the Court of Louise-Marie Gonzaga', *Rocznik Filozoficzny Ignatianum*, 27-2 (2021), pp.1 79–198.

116. See, for example: *Jean Picard et les débuts de l'astronomie de précision au XVIIe siècle – actes du colloque du tricentenaire* (Paris: Éditions du Centre National de la Recherche Scientifique, 1987).

117. Burattini, *Misura Universale*, *Proemio*.

118. To quote just some examples : (1) Jean de Hautefeuille's spring vertical escapement of 1674 (J. de Hautefeuille, *Factum touchant les pendules de poche*, 1676) for which he accused Huygens of plagiarism, but this invention could not work properly; (2) Hautefeuille's magnetic pendulum (J. de Hautefeuille, *Pendule perpétuelle avec un nouveau balancier*, 1678) that cannot work because its motion is based on non-physical laws; (3) most of Kochański's unusual escapements described in G. Schott's *Technica Curiosa*; (4) Leibniz's double-balance clock which could not work and was only a thought experiment, see https://gallica.bnf.fr/ark:/12148/bpt6k56526h/f82.item; (5) all attempts at making perpetual motion clocks before and after Burattini. These were all just thought experiments that could not be realized in practice.

form of ultimate theory where all the physical quantities are reduced to one, invariant in time, and thus *eternal*. Although this idea may have religious roots as it is said that God had arranged all things 'by measure, numbers and weights' (Book of Wisdom), it is more likely that Burattini was influenced by the scientific theories of his time, including Descartes's'eternal truths'; indeed, it is easy to see a connection between the notion of 'universal measure' and the 'universals' (*universaux*) described by Descartes, among which are numbers, magnitude or time, abstract notions above the existing, all linked to the notion of *measure*.[119] It was also Descartes who renewed significantly the concept of *mathesis universalis*, going deeper into the idea of universality applied to all accessible knowledge. Interestingly, it is this same principle that was used in 2019 to redefine the units of the International System based on the fundamental constants of physics.

Burattini's search for universality is accompanied by transversality. We can see that he applied to clocks some technical solutions resulting from other works of his, such as the hydraulic winding system or the brass or silver wire, both of which were used for other purposes. His extensive knowledge of astronomy, mechanics and optics allowed him to apply the advances made in one discipline to others, at a time when many scholars embraced all the intellectual arts as a whole.

For all these reasons, one can say that Burattini's work is definitely linked to the social context and the scientific mentality of the seventeenth century.

It is unfortunate that none of the timepieces made by Burattini appears to have survived. More detailed descriptions of them, especially of the 'pendulum watch', may exist in the Medici inventory of 1690,[120] which includes the aforementioned Coster clock sent to the Grand Duke by Burattini. It is also likely that Burattini gave other clocks to the King of Poland John Casimir; the inventory of his possessions drawn up at his death in 1672 shows that he owned some exceptional timepieces, including two clocks indicating the seconds, one of them equipped with a cross-beat.[121] All his goods were sold in 1673 and no one seems to know what happened to them; there are two clocks presently known that he may have owned, one in the National Maritime Museum,[122] the other in the British Museum.[123]

New future discoveries may provide us with more information about Burattini's original creations and his discreet – but technically exciting – contribution to the development of the first pendulum clocks.

Acknowledgments

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119. R. Descartes, *Les Principes de la Philosophie, Escrits en Latin, Par René Descartes. Et traduits en François par un de ses Amis* (Paris: Pierre Des-Hayes, 1647), pp. 39–41 and pp. 68–75.

120. *Guardaroba Medicea*, 959, Archivio di Stato di Firenze.

121. P. G. Poole, 'The Casimir Inventories', *Horological Journal*, 107-2/3/4 (August / September / October 1964), 14–15 / 20–21 / 24–26.

122. Víctor Pérez Álvarez, 'The universe on the table. The Buschman Renaissance clock of the National Maritime Museum', *Antiquarian Horology* (September 2018), 342–360.

123. https://www.britishmuseum.org/collection/object/H_1867-0716-4.