GALILEO, HUYGENS AND THE PENDULUM CLOCK: ISOCHRONISM AND SYNCHRONICITY[1]

INTRODUCTION

Filip BUYSE*

On the 2nd October 2017, the Noble Prize in Physiology or Medicine was awarded to three researchers who were able to elucidate how the internal, biological clock of living organisms adapts itself so that it is synchronized with the Earth's revolutions. In the press release of the Noble Prize committee we read the following introductory paragraph:

> Life on Earth is adapted to the rotation of our planet. For many years we have known that living organisms, including humans, have an internal, biological clock that helps them anticipate and adapt to the regular rhythm of the day. But how does this clock actually work? Jeffrey C. Hall, Michael Rosbash and Michael W. Young were able to peek inside our biological clock and elucidate its inner workings. Their discoveries explain how plants, animals and humans adapt their biological rhythm so that it is synchronized with the Earth's revolutions[2].

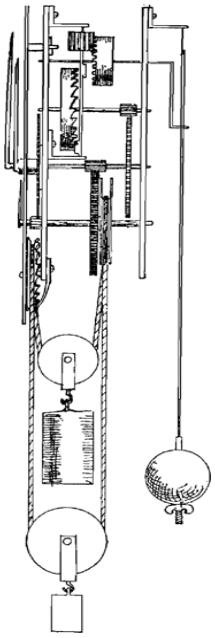
Christiaan Huygens (1629-1695) was the first physicist to observe and analyze the phenomenon of synchronization. More precisely, the Dutch physicist and astronomer observed on the 1st March of 1665[3] that two pendulum clocks which were standing in front of him started to move in phase. He couldn't believe his eyes and tried to find a mechanical explanation for this spectacular observation "which no one ever would have thought of. ". Initially, he interpreted 'l'accord merveilleux' as a kind of 'sympathy' but already one month later[4] he discovered the real mechanical cause of this odd phenomenon.

In this volume, Dr. Kurt Wiesenfeld explains how his research group has examined synchronization by means of reconstructions of Huygens' pendulum clocks. In another paper, Dr. Filip Buyse argues that Spinoza was in contact with Christiaan Huygens during the period of his spectacular invention. Hence, the Dutch physicist and astronomer might have influenced and inspired Spinoza (1632 -1677) in his views on the agreement between bodies in the universe. This would resolve Spinoza's otherwise paradoxical phrases in his answer to Robert Boyle's question, in his *Letter 32* (1665) to the secretary of the Royale Society. Furthermore, Dr. Maxime Rovere

* Visiting Fellow at the Centre for the History and Philosophy of Physics at St Cross College, University of Oxford, 61 St Giles', Oxford OX1 3LZ, UK. Visiting Researcher at the Vossius Centre of the University of Amsterdam. E-mail: f.a.a.buyse@gmail.com

argues in his paper that Spinoza might also have been influenced by the physics of oscillating pendulums in his theory of emotions.

Fig. 1: This is a drawing of Huygens's Pendulum Clock, which the Dutch physicist included in his *Horologium* (1658)



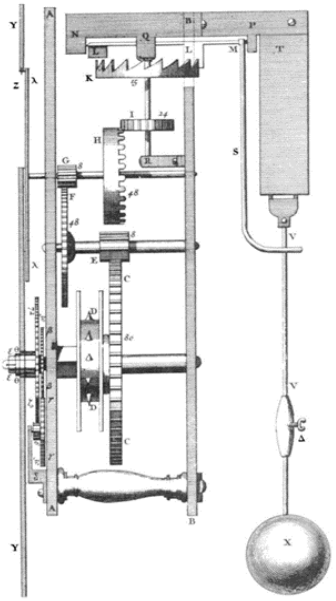


Fig. 2: This drawing is from Christiaan Huygens's treatise *Horologium Oscillatorium,* published in 1673 in Paris. It records improvements to the mechanism that Huygens had illustrated in the 1658 publication of his invention, titled *Horologium*

Christiaan Huygens designed his pendulum clock in 1656 and it was built by his instrument maker Salomon Coster (ca.1622-1659). He patented his sophisticated

machine in 1657. However, Huygens was not the first to conceive a pendulum regulated clock. As he reveals in his *Horologium* (1658), his invention was based on Galileo's invention of the principle of isochronism. (A principle which is discussed by Dr. Mohammed Abattouy in this special issue.) There is historical evidence that Galileo had already started to do research on the movement of a pendulum in 1603. At that moment he was professor in Padua. In this issue, Fabrizio Bigotti and David Taylor reconstruct and discuss a seventeenth[th] century medical instrument which is an application of the the pendulum. This *pulsilogium* was probably invented by one of Galileo's colleagues, Santorio Santori (1561-1636).

Interestingly, Galileo (1564-1642) sent on the 15[th] August 1636[5] a letter to the States General of the Netherlands with his proposal for a method for the determination of the longitude at sea based on the satellites of Jupiter. He had discovered these medicean planets in 1610. Importantly, in this letter he gave already - 20 years before Huygens's invention - a first version of a kind of pendulum-regulator time-keeper:

> I have such a time -measurer that if 4 or 6 examples of this instrument were constructed, and if they were allowed to operate at the same time, we would find that in confirmation of their accuracy, the times measured and indicated by these time-measurers would show differences of only one second, not only from hour to hour, but from day to day and from month to month, so uniform would be their operation; these clocks are really admirable for the observers of motion and celestial phenomenon, and in addition, their construction is very simple and far less subject to outside influences than are other instruments which have been invented for a similar purpose[6].

It is hard to believe that Christiaan Huygens' did not know about Galileo's invention given the fact that his father, the poet and diplomate Constantijn Huygens, mediated[7] several times in the difficult correspondence between Galileo and the States General concerning his proposal. Hence, he knew about Galileo's invention and could have informed his 'Little Archimedes.' Moreover, there are several other elements that confirm that it is likely that Christiaan Huygens must have known of Galileo's design although there is no hard-historical evidence.

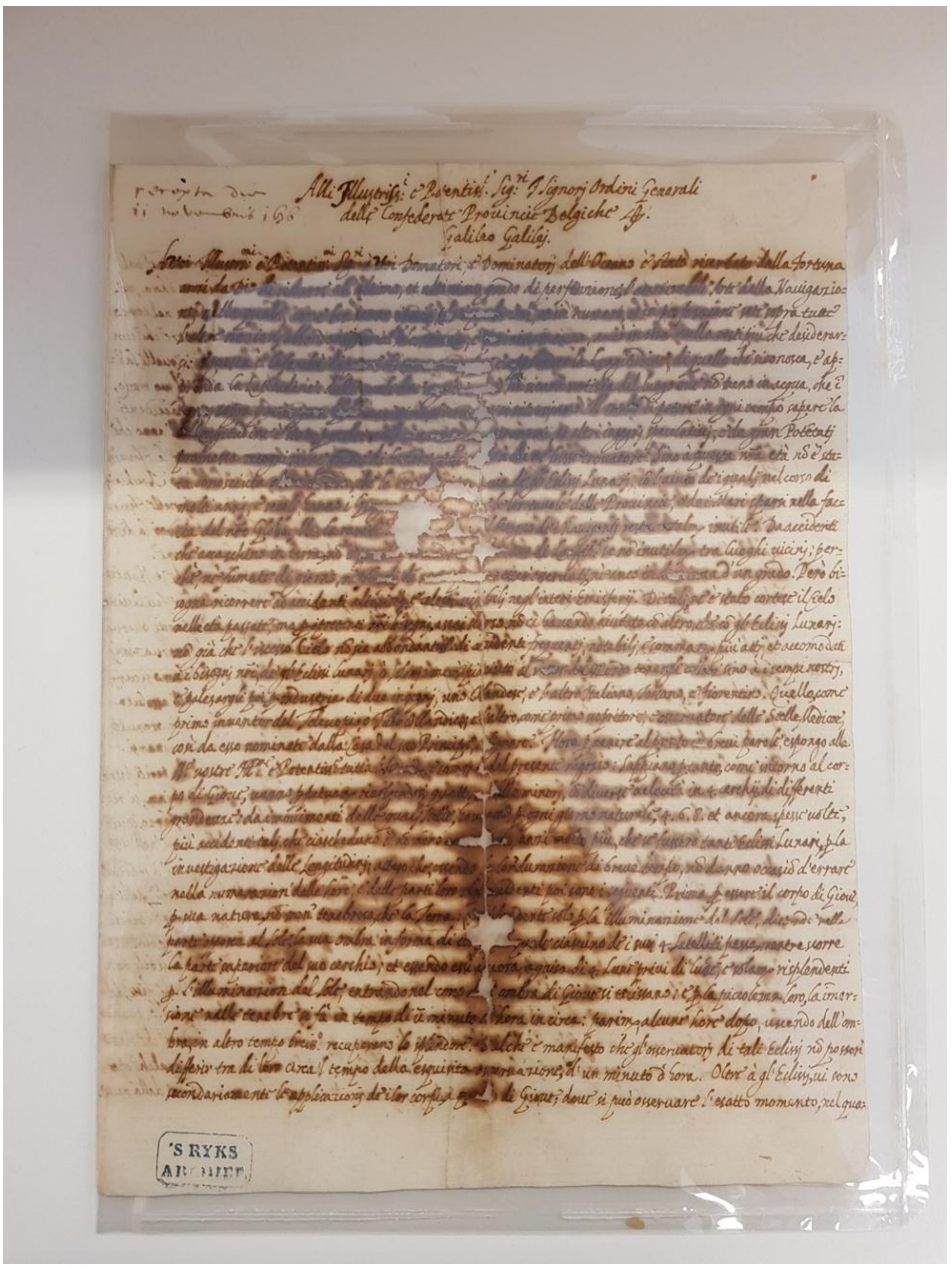


Fig. 3: This is a picture of the first page of Galileo's letter to the States General of the Netherlands with his proposal for a method for the determination of the longitude at sea (This letter - dated August 15, 1636 - is in the Dutch National Archives in The Hague).

Firstly, the Dutch physicist knew the work of the Italian physicist (such as his physics of the pendulum) very well. Indeed, he had all published works of Galileo in his personal library and much of his own work can be conceived as a prolongation of that of the Italian master he admired[8]. Among others, he had for instance *L'usage du cadran ou de l'horloge physique universel*[9] published in 1639 in Paris in his possession. Secondly, it is important to notice that one year before his invention of his pendulum clock the author of the *Horologium oscillatorium sive de motu pendularium* (1673) wrote a letter to Andreas Colvius (1594-1671) asking him for copies of Galileo's unpublished works which the Dutch minister had brought form Italy after his stay at the Dutch Embassy in Venice. In the same letter, Huygens emphasized that he was especially interested in Galileo's writings concerning the determination of the longitude: "*Expectabo invicem quae ad longitudinum scientiam pertinent manuscripta, et si quae alia Galilaei posthuma possides; restituturus cum tibi visum fuerit.*" He even gave Colvius a newly invented microscope as a present with the hope to receive the copies in return. Within a month, Colvius sent the copies of the manuscripts to Huygens. In sum, it is likely that Huygens knew about Galileo's idea to construct a pendulum regulated clock although he always denied that he did. On April 14, 1660, he wrote to his close friend Ismael Bouilliau: "neither I nor any knowledgeable individual in this country, as well as I know, had ever speak of such a thing before I published it."[10].

After Galileo's death in 1642, the discussion concerning the invention of the pendulum clock continued and a huge controversy developed between Huygens and the circle around Galileo's last pupil and first biographer. Viviani (1622-1703) defended his master and accused Huygens of plagiarism[11]. On August 20, 1659, he explained - in this letter to Prince Leopold after having heard about Huygens's invention – in detail how Galileo (who had meanwhile become blind) had designed for the first time a pendulum regulated clock and how his son Vicenzio Galileo had tried to construct this clock with the help of a locksmith:

> One day in the year 1641, whilst I was living with him in his country house in Arcetri, I *recollect* that it came into his mind that the pendulum could be adapted to clocks driven by weight or spring, in the hope that the perfect natural equality of its motion would correct the imperfections of mechanical construction. But, being deprived of sight and unable himself to execute the plans and models which would be required to ascertain which would be best adapted for carrying out this project, he communicated his idea to his son Vicenzio, who had come out one day from Florence to Arcetri. They had several discussions on the subject, with the result that they fixed upon the method, of which the accompanying drawing is a copy; and they decided to proceed at once with its execution, in order to determine what were the difficulties, which, as a rule, in the construction of machines, a theoretical design does not reveal. But Vicenzio, being desirous to construct the instrument with his own hands, for fear lest the artificers who might be employed should divulge it before it had been presented to the Grand Duke and to the States-General of Holland for the measurement of longitudes, kept

putting off its execution, and a few months later Galileo, the author of this admirable invention, fell ill, and died on January 8, 1642. As a consequence, Vicenzio's enthusiasm cooled down, so that it was not until the month of April 1649, that he took in hand the manufacture *of the present clock (del presente orivuolo)* made in accordance with the conception (*concetto*) which his father had already imparted to him in my presence.
Vicenzio Galilei engaged a young locksmith, who had some experience in construction of large wall clocks. He caused him to make the iron framework, the wheels, and their arbors and pinions, but without cutting them, and he executed the rest of the work with his own hands.[12]

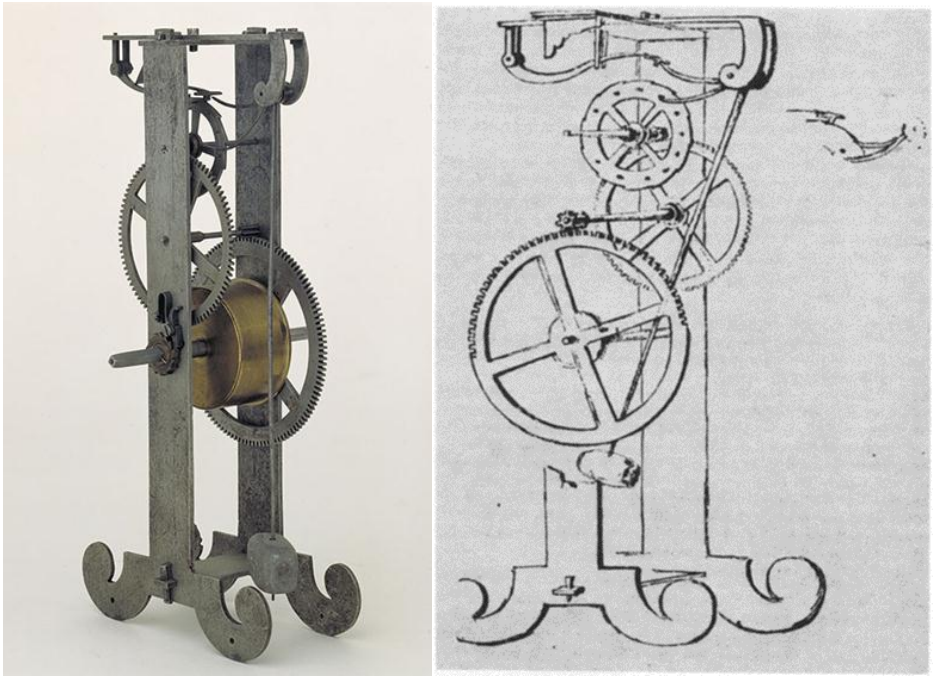


Fig. 4 (Right): Drawing made in 1659 by Vincenzo Viviani of the Galilean clock model in its unfinished state of 1649.
Fig. 5 (Left): reconstruction of Galileo's pendulum clock by Eustachio Porcellotti (1879) based on Vincenzo's Galilei's model.

Before Huygens's invention, mechanical clocks existed already for a very long time[13]. Indeed, there existed already a long tradition of mechanical clocks which goes back to the Middle Ages and even earlier. A typical mechanical clock is basically composed of five different elements. And, each has its own specific function: the energy source that every clock needs to make it work (e.g. the potential energy of a mass hanging at a certain height or the elastic energy of a spring), wheels for the transfer of the energy through the clock, an escapement to stop the potential energy

from escaping all at once, the controller which controls the speed of the escapement and the time indicator which is the part of the clock that indicates the time to the viewer. However, the difference between the pendulum clock and other mechanical clocks is that a pendulum clock has a pendulum as a regulator.

The pendulum clocks were much more adequate than other mechanical clocks. Consequently, as timekeepers, their invention had an enormous impact on the social and professional life of people. However, they were also applied as metaphors and mechanical analogies by philosophers. Before Huygens's invention, philosophers such as Descartes (1596-1650) and astronomers such Kepler (1571-1630) had already applied the clock metaphor. However, Huygens's invention renewed and stimulated this application. Moreover, in areas such the mind/body problem and the conception of the world, it became one of the leading metaphors of the seventeenth[th] century. In this volume, Dr. Matteo Favaretti examines Leibniz's application of the clock.

References

[1] In this introduction, I use the following abbreviations: *Opere* = Galilei Galileo (Ėd. par Favaro, A. et Del Lungo, I.), *Le Opere di Galileo Galilei* (Edizione Nazionale). 20 vols, Florence, Barbera, 1890-1909, OCH = Christiaan Huygens. *Œuvres Complètes de Christiaan Huygens* (Publ. par la Société hollandaise des sciences ; La Haye: M. Nijhoff, 1888-1950).

[2] The press release can be found on the following site: https://www.nobelprize.org/nobel_prizes/medicine/laureates/2017/press.html, 06/12/2017.

[3] Cf.OCH XVII, 185.

[4] See *Letter N°1362* de Christiaan Huygens to Robert Moray (27 March 1665).

[5] Cf. *Opere*, XVI, 463-469.

[6] From Galileo's letter (dated August 15, 1636) to the States General of the Netherlands. Cf. *Opere*, XVI, 463-469. The English translation is by Silvio A. Bedini. In the original text, Galileo writes: " […] Finalemente, circa il 4° requisito, io ho tal misurator del tempo, che se si fabbricassero 4 o 6 di tali strumenti et si lasciassero scorrere, troveremmo (in confermazione della lor giustezza) che i tempi da quelli misurati et mostrati, non solamente d'hora in hora, ma di giorno in giorno et di mese in mese non differirebbero tra di loro nè anco d'un minuto secondo d'hora, tanto uniformemente caminano : orologii veramente pur troppo ammirabili per gl'osservatori de i moti e fenomeni celesti ; et è di più la fabrica di tali strumenti schiettissima e semplicissima, et assai meno sottoposta all'alterazioni esterne di qual si voglia altro strumento per simile uso ritrovato."

[7] See OCH XVII, 44; OCH XVII, 59-60; OCH XVII, 80; OCH XVII, 73-74; OCH XVII, 289; OCH XVIII, 149-150; OCH XVIII, 176 and OCH XVIII, 181.

[8] See the appendix of *letter N° 2790* from Christiaan Huygens to Pierre Bayle (26th February 1693).

[9] Galilei, G., *L'usage du quadran ou De l'horloge physique universel sans l'ayde du soleil ny d'autre lumière* (Paris : Hachette Livre BNF, 2016).

[10] OCH III, 65.

[11] See Bedini, S. A., *The Pulse of Time - Galileo Galilei, the determination of longitude, and the pendulum clock* (Firenze: Leo S. Olschki, 1991).

[12] Letter from Viviani to Prince Leopold (August 20, 1659). GG XIX, 655-657. The translation is by J.D. Robertson. Cf. Roberston, J.D., *The evolution of Clockwork* (London: Cassell Company, 1931), 91.

[13] See North, J., *God's Clockmaker – Richard of Wallingford and the Invention of Time* (London: Continuum, 2005) and Edwardes, E.L., *The Story of the Pendulum Clock* (Altrincham: John Sherratt and Son Ltd., 1977).