Dutch Contributions to the Synchronization of Pendulums
Hans de Zeeuw¹, Kees Grimbergen²

Christiaan Huygens: Huygens Synchronization

Christiaan Huygens (14 April 1629 – 8 July 1695) is the famous 17th century Dutch physicist, well known for a great number of achievements in astronomy (telescopes, ring and moon Titan of Saturn), statistics (first statistical treatises) and physics (collision laws, wave theory, relativity). He was also interested in horology with, as main contributions, the introduction of the pendulum in the clock (1657), modelling isochronism and the introduction of the balance wheel with spiral spring (1675).

He was also the first to observe and describe synchronization of pendulums. Being ill and staying in bed in his room with two nearly identical pendulum clocks in February 1665, he noticed an interaction between the two clocks leading to an anti-phase swing of the two pendulums.¹ In the week after his recovery he performed a number of meticulous experiments with the two clocks suspended on a bar put across the backs of two chairs,¹

From these experiments he defined a number of mechanisms which are known as “Huygens Synchronization” and still in debate in the 21st century.² He also introduced the term “sympathia”.

His findings were later adopted by Antide Janvier (1751-1835) who built several clocks (longcase and table clocks) with two pendulums, each with their own train, between 1800 and 1810.²

Also Louis Abraham Breguet (1747-1823) applied two pendulum systems in several longcase clocks (ca 1825). He also developed watches with two balances and two independent going trains.

Mart. 1. Hora 10 mat. praecebat A tribus secundis.

[Fig. 76: ]

Utique horologio pro fulcro erant fedes duas [Fig. 76] quarum exiguus ac plane invisibilis motus pendulorum agitatione excitatus sympathiae praeceps causae fuerit,

¹. Christiaan Huygens’ analysis 3 of the behaviour of two pendulum clocks attached to a beam supported by chairs (February 22, 1665); note the term “sympathiae” in the text below fig. 77. from reference 3, www.gallica.bnf.fr.

1. Medical Physics Dept, Academic Medical Centre, University of Amsterdam
In more recent times, the Swiss watchmaker François Paul Journe designed his ‘Resonance’ series of wristwatches, 3, and produced several versions between 1984 and 2006. A number of double pendulum clocks have been developed in modern times and there is of course the ‘Project 150’ 3-pendulum clock being presented to the Institute this weekend.

**Felix Andries Vening Meinesz : Gravity Measurements (1915 – 1939)**

Gravity can be measured using pendulums. In the early 20th century there was a great interest in gravity and the aberrations caused by geological structures, especially in the sea. The Dutch geodesist Felix Andries Vening Meinesz, 4, decided to use a submarine for gravity measurements at sea avoiding the motion of waves at the sea surface. He spent many years with his submarine expeditions travelling more than 100,000 nautical miles in the oceans and seas. 5 He designed special two and three pendulum systems which enabled him to measure gravity with sufficient accuracy. As a PhD student his research on pendulum measurements was presented in a thesis 6 he defended at Delft University of Technology March 26, 1915. With his pendulum systems he was able to show the negative anomalies in gravity along the oceanic trenches. His discoveries could be explained only with the development of the theory of plate tectonics in the 1950s.

**Henk Nijmeijer et al: Experimental results on Huygens Synchronization (2006)**

The synchronization of pendulums as found by Huygens in 1665 is still a subject of modern research of several international groups. There is also one Dutch research group active in this field since 2000, the Theoretical Mechanics Department of Eindhoven Technical
University, headed by Professor Henk Nijmeijer. Among other experiments, he showed that a platform suspended by leaf springs with two metronomes, 5, which can translate horizontally, may show different synchronization phenomena dependent on the mass of the platform and the damping in the system. In addition to anti phase synchronization, in phase synchronization can be obtained but also intermediate synchronization and intermediate chaotic regimes of oscillation. The authors conclude their reports stating that “much work remains to be done in this field with important applications in dynamic control”.

Amateurs: Hans de Zeeuw, Jan Pool: Design of two-pendulum clocks

Not only in research but also with amateurs, there is a vivid interest in the synchronization of pendulums. There are many hobbyists interested in understanding and improving the mechanisms of pendulum clocks following the developments in the early 20th century. Of course, the practical use of these developments is overshadowed by the developments in 20th century time measurement leading to atomic clocks with more than 6 orders of magnitude higher accuracies.

In the Netherlands there are two amateurs experimenting with double pendulum systems.

Hans de Zeeuw, an active designer of clocks, started in 2003 building regulators according to the design of Riefler. Riefler was a talented German engineer who provided observatories all over the world with over 600 accurate timekeepers. The important design aspect was the so-called free pendulum escapement he patented in 1889. The Federkrafthemmung (spring force escapement) was most reliable and popular, but Riefler also developed the Schwerkrafthemmung (a form of gravity escapement), 6. This gravity escapement was technically much more complicated and Riefler produced only two regulators with this escapement (although he made many hundreds with the

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5a. Setup with two metronomes on a platform suspended on leaf springs as used by Nijmeijer (reference 4).
5b. The development of anti phase synchronization within 300 seconds starting in phase. For the mechanical parameters, see reference 4.
6. Riefler’s gravity escapement. The hatched part is connected to the pendulum and lifts the gravity arms k₁ and k₂ via O₁ and O₂.

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Building a regulator with this complex escapement is thus quite a challenge for amateurs. The results of the version built by Hans de Zeeuw, 7, were very good. The clock was built with high quality materials (stainless steel, brass, titanium and ruby), a quartz pendulum rod was used with high mechanical stability, with knife-edge suspension and full temperature and barometric compensation. After completion, however, external circumstances in Zoeterwoude (in the west of Holland near Leiden) with its soft soil, heavy tractors passing by and heavy winds, influenced the sensitive design, sometimes even stopping the regulator.

This made Hans de Zeeuw decide in 2005 to apply two pendulums in his new design in the hope that the two pendulums would be able to compensate for the disturbances of the environment. He chose a construction with two going trains and one dial with two seconds hands. Each going train had the same high quality design with its own gravity escapement making this a unique clock equal the number of...
gravity escapements made by Riefler himself. The pendulums could be adjusted to swing in anti phase and the accuracy of the clock was high (in the order of 0.4 ppm during 15 hours). Although the sensitivity for disturbances was decreased, the two pendulums in anti phase were not able to cope with the severe disturbances of passing heavy tractors. These still could stop the clock regularly. The experiments and analysis of the behaviour of the clock are continued looking for better results.

Jan Pool, another Dutch amateur, Bunnik, very recently took a different approach: selecting a two pendulum system with electromagnetic drive and opto-electronic control, 8. His pendulums also had quartz rods, knife suspension and barometric compensation. His clock appeared to have even longer response times than that of Hans de Zeeuw; sometimes a stable anti phase oscillation was only obtained after more than 40 hours! And in both clocks stable anti phase oscillation could only be obtained after adjusting the period of swing of both pendulums within 1 sec per day (< 10 ppm).

8a. Two pendulum clock with quartz pendulum rods, electromagnetic drive and opto-electronic control.

8b. Knife suspensions and coils for the electromagnetic drive.

8c. MICROSET recording (6.8 hr). In blue the clock rate is shown (5 microsec per division) (temperature (green) and barometric pressure (red) have also been recorded).

Conclusions

Synchronization of pendulums is still not well understood.

The mechanisms of the so-called Huygens Synchronization as defined by this great scientist in March 1665, are still subject of research and debate in the 21st century.

The Dutch contributions to the research and application of double pendulums have been reviewed.

In addition to the first experiments and observations by Christiaan Huygens, two- and even three-pendulum systems were applied with success to the measurements of gravity worldwide by Felix Andries Vening Meinesz, a Dutch geodesist using the early submarines of the 20th century to explore the anomalies in gravity along the oceanic trenches.

A Dutch research group active in exploring synchronization of pendulums since 2000 is the Theoretical Mechanics Department of Eindhoven Technical University, headed by Professor Henk Nijmeijer working in the field of dynamic control.

Two amateurs designing two pendulum systems could illustrate the complex behaviour of these systems trying to exploit the stabilizing properties of anti phase oscillations for the improvement of mechanical timepieces.