Switching on time

A themed exhibition at the studieverzameling

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For over a hundred years, there has been a need to execute and/or record actions at the right time. This could include an acoustic signal to indicate the start and the end of working hours in the factory, a signal at the start and the end of classes, and switching lighting on or off at a fixed time. But there is also 'switching on time' when using, for example, vault clocks, night watchman clocks, pigeon clocks, time clocks, and the like. A themed exhibition has been set up around this subject at the Faculty's Study Collection. Some hundred objects related to this theme are exhibited in the basements of the EEMCS low-rise building.

Figure 1. *An overview of the exhibition*

In this exhibition, special attention is paid to the principle of master and slave clocks (in Dutch, we refer to such clocks as to mother and daughter). When designing these timepieces - around the year 1900 - the idea was based on having an accurately running central clock (master clock) passing on the correct time to a large number of secondary timepieces (slave clocks). Passing the right time often went through electric pulses, but pneumatic systems were also used. The concept of this type of system is called a time distribution network.

To give you an example of such a time distribution network: some 125 years ago, the railways needed to display the same, correct time at all of their stations. After all, they were driving according to the timetable. Not every traveler had a pocket watch - the wristwatch didn't exist yet - and the tower clock didn't necessarily show the correct time. The idea then arose to distribute the right time; if a precision timepiece somewhere centrally ran precisely on time, the time of that master clock could be passed on to a large number of slave clocks, which would then by definition also display the correct time. That was the general idea.

At that time, the starting point for the design of a master clock was a clockwork with a pendulum, driven by a raised weight or a wound spring. A pendulum clock is a timepiece, the regular running of which is regulated by a reciprocating pendulum. When the time in which the pendulum swings back and forth is practically constant, the clock will run smoothly. This uniformity allows time to be measured reliably and accurately.

A pendulum clock requires a precise adjustment of the pendulum (length); otherwise, the clock will run too fast or too slow. By the way, the pendulum time is not determined by the material or weight of the pendulum (lens) but by the length of the pendulum stem.

The aim of the quest for improvement of the accuracy of pendulum clocks was to achieve the 'ideal' pendulum. After all, when the pendulum movement is even and thus the pendulum time constant, the timepiece's accuracy is optimal.

The pendulum period of a pendulum is shown in the next formula: $T= 2\pi\sqrt{(l/g)}$, with l = the pendulum length in meters and g = the gravitational acceleration in meters per second squared.

In the pendulum time T, the pendulum swings once back and forth. The letter t represents half the pendulum period, either once forth or once back.

Because the above formula only applies to small pendulum angles, the deflection from its rest position (= pendulum amplitude) should not be too great. This formula also shows that a constant pendulum length is crucial for accurate time measurement.

A pendulum with a length of about 1 meter has a pendulum time T of 2 seconds and a t of 1 second. A seconds impulse could then be generated by a switching contact on the pendulum rod. Or a minute impulse using a counting wheel.

The distribution of those electrical pulses to slave clocks went through electrical wires. For the railways, use was made of the existing telegraph lines on poles along the railway embankment. When the distance to be bridged was too large, pulse amplifiers (line amplifiers, relays) had to be used in the wiring.

In the quest to improve the accuracy of pendulum clocks - de facto optimizing the accuracy of the pendulum movement - a number of changes were made to the respective master clocks over the past decades. For example, compensation for the change in the length of the pendulum stem due to temperature differences. After all, the pendulum length has a direct influence on the pendulum time. Several techniques the respective clock designers have used along the way in optimizing the accuracy of the pendulum movement are visible in the exhibited objects.

One of the many ways to blueprint the ideal pendulum was by eliminating as much as possible the adverse effects of the driving force of the clockwork (weight or spring tension) on the regular course of the pendulum. Achieving the ideal pendulum came one step closer by removing the drive weight or the winding spring. But also removing gears, pinions, and clock hands further improved the pendulum accuracy. Removal of the drive introduced a new problem; how should mechanical energy be supplied to the pendulum without disturbing the regular course of the pendulum motion? Various interesting solutions were devised for this; a number of these alternative pendulum drives can be admired at the master clocks present at the theme exhibition.

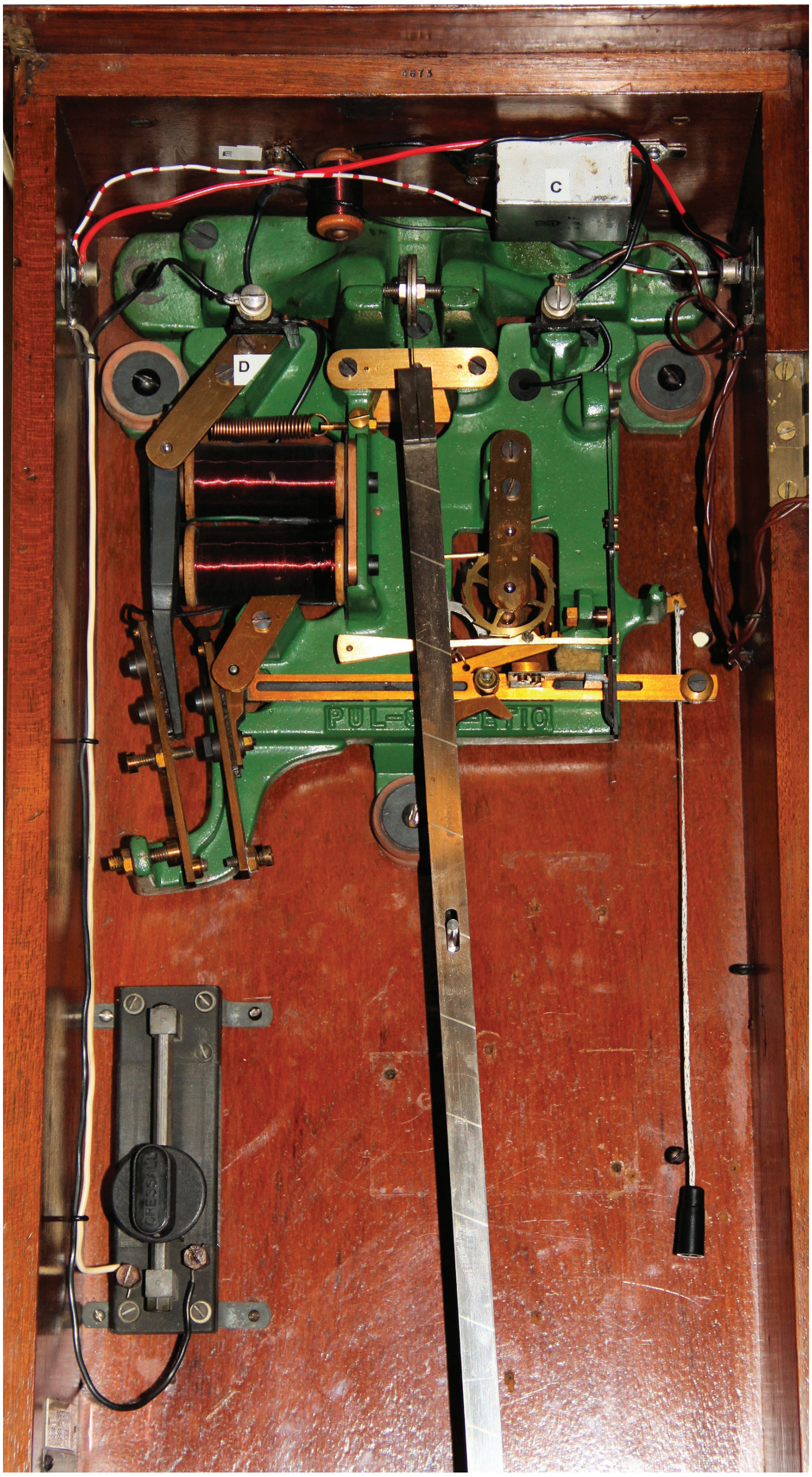

Figure 2. *A gravity arm driven pendulum of a PUL-SYN-ETIC master clock, built by GENT of LEICESTER (1938)*

General clock precision from 1650 to the present

The accuracy of a timepiece is usually indicated by its day-to-day running and deviations from the real time. This indicates the number of seconds (or fractions thereof) the clock is running ahead or lagging during a day. This gait also indicates the number of days or years the timepiece has needed to gain or lose 1 second.

Over the past few centuries, the accuracy of timepieces has increased enormously. The pendulum clocks from around 1660, designed by Christiaan Huygens, ran one second ahead or behind every 3 hours. A big step forward in terms of accuracy was taken when Marrison invented the quartz clock in 1928 with a deviation of maximum one second every three years. In other words, the quartz clock is about 10,000 times more accurate than Huygens' pendulum clock.

Over the past fifty years, the performance of clocks has improved even more rapidly; in particular (Cesium or Rubidium) atomic clocks have contributed to this development. An atomic clock uses the vibrations of atoms as the basis for measuring time. The frequency of these vibrations is so extremely constant and independent of the environment that the deviation of an atomic clock is almost negligible. The first atomic frequency generators around the year 1955 (atomic clocks) based on cesium-133 were only ahead or lagging by one second in 300 years, while later standards will only do so after 300,000 years. At the turn of the century, an accuracy of one second in 3 million years was achieved. In 2019 we noted an accuracy of one second every 5 billion years (i.e. inaccuracy is 6 x 10-18). Today there are ytterbium-based coupled atomic clocks with an accuracy of one second every 15 billion years.

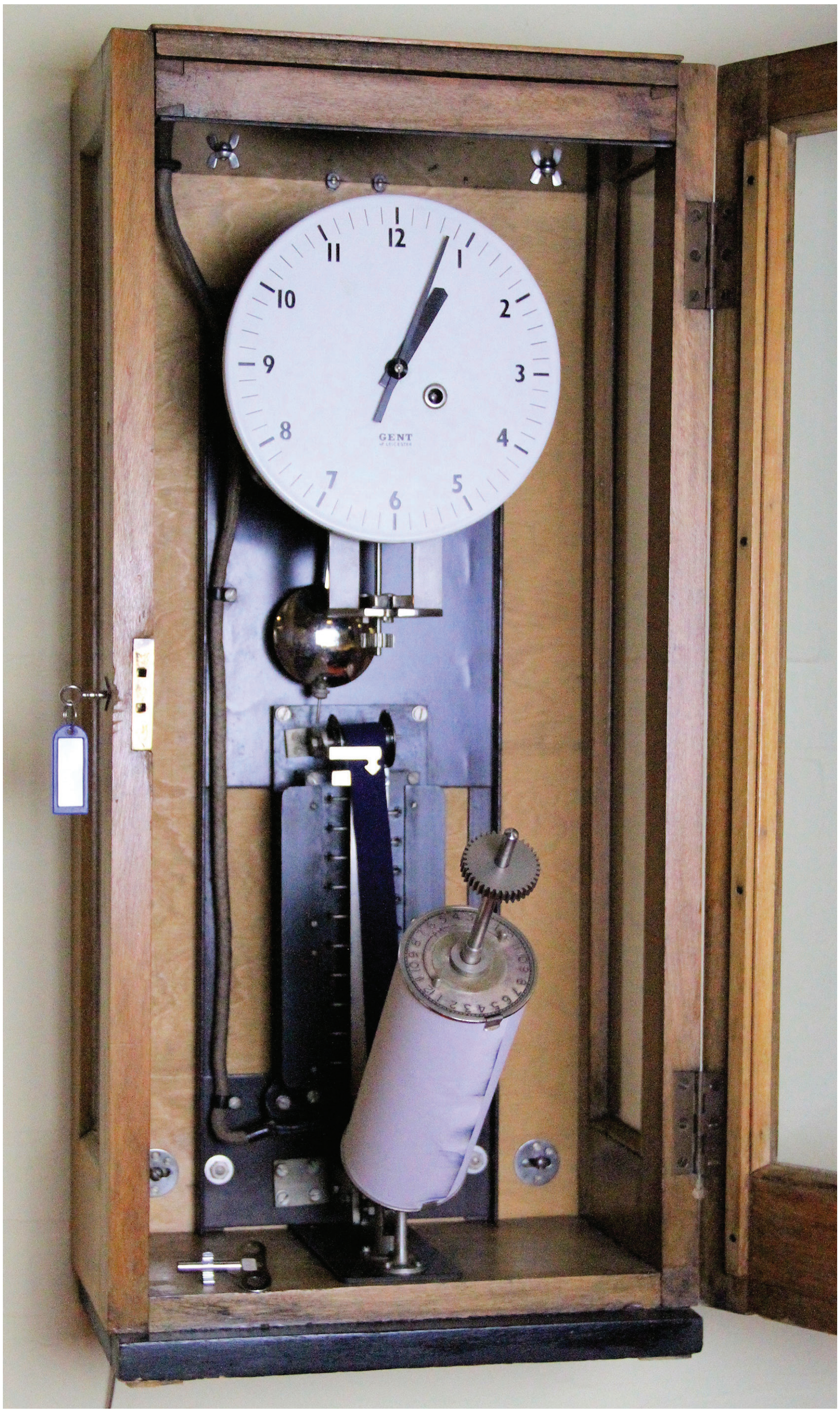

Figure 3. *Watchman's Tell Tale Clock by GENT of LEICESTER with registration cylinder (around 1950)*

Jump to the present

Today, the application of distributing time has become much more widespread. Just think of the many Radio Controlled clocks in use (based on the airwave signal DCF 77). But also the time displayed on our mobile phones, the time in satellite navigation systems such as GPS, time on the internet (Network Time Protocol NTP), the time on our digital radio receivers (DAB), smartwatches, etc.

In short: the need for 'always the right time in every place' has remained unabated throughout the years. However, the underlying techniques for the accurate determination and the dissemination of that time have changed greatly in recent decades; i.e. the

• master clocks - originally pendulum clocks, later quartz clocks - have now become atomic clocks with unprecedented accuracy
• dissemination of time information is no longer wired but has become wireless, via both the ether (DCF 77) and satellite
• distribution networks have grown from local and national to continental (DCF 77 in Europe) and global (GPS, NTP)
• decentralized clocks (slave clocks) have become our mobile phones, GPS systems, Internet time, DAB radio receivers, smartwatches, etc.

In itself, this evolution is also an excellent example of ***switching on time***…