Antoine Redier's ingenious *Comparateur Chronométrique* for precise time comparisons

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Timekeepers with conventional escapements have an intermittent action, albeit regular – their seconds hands advance in steps of one second, half a second, or some fraction of a second, with each release of the escapement. Because of this they cannot be synchronised exactly with one another, nor with a time signal or an event under observation, and some degree of judgement is required. To overcome this problem the nineteenth century French maker Antoine Redier devised his ingenious 'Comparateur Chronométrique' where the movement of the seconds hand can be advanced or retarded while the instrument is running, thus making exact synchronisations and comparisons possible and allowing differences to be determined.

Antoine Redier, 1817–1892

Antoine-Jean-Joseph Redier was born in Perpignan, in the southernmost region of France, in 1817 and as a boy he worked for his father who was a goldsmith. At the age of fifteen he moved to Paris and was one of the first pupils to be enrolled in the new school for watchmaking, established in 1832 under the celebrated maker Louis-Frédéric Perrelet. Of all Perrelet's pupils, Redier went on to become the most remarkable.[1]

Redier's talents had been recognised at an early age by the astronomer François Arago who was a friend of the family. Arago was instrumental in Redier's move to Paris, and in his application to join Perrelet's school where Redier gained first place in the tests for admission. On the completion of his training, Redier worked for the chronometer maker Henri Robert for three years and then, in 1842, he set up on his own by acquiring the business of Duchemin. Redier had an inventive mind and turned his attention not only to sophisticated timekeepers, but to all kinds of instruments for scientific, medical and industrial purposes. He participated in the French Expositions held between 1844 and 1878, either as an exhibitor or as a member of the jury. For his work he was awarded the *Croix de la Légion d'Honneur* in 1863 and was later raised to an *Officier*. In 1877 he received a gold medal from the Société d'Encouragement pour l'Industrie Nationale, and for fourteen years he served on its committee for mechanical arts. Later in life Redier established a workshop with his son at Saint-Nicolas d'Aliermont, where he is commemorated with a bust (Fig. 1) in the Musée de l'Horlogerie.

Redier died in 1892 and Paul Garnier Jnr. described his life and work in an extensive obituary which was published in *Revue Chronométrique*.[2] Redier was himself a

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1. Phillip Arnott, 'Constant Force Chronometer, N°1, Attributed to Paul Garnier', *Antiquarian Horology*, 33/1 (September 2011), 55–56; 66–67. Perrelet's pupils were Redier, Dumas, Gannery, Gailan, Gautier, Lecoq, Leport, Prieur, Couvreur, Brulé and Wolf (the latter three did not complete their training). Perrelet resigned in 1840 and Charles-Auguste Berthoud took over the management of the school.

2. Paul Garnier, 'Antoine-Jean-Joseph Redier (1817–1892) – Notes sur sa vie et ses travaux', *Revue Chronométrique*, Vol.XVII (1892–93), 181–185. Redier's timekeepers included clocks with astronomical complications and barometric pressure compensation. His instruments included barometers, thermometers, hygrometers, counters and recording devices. He published historical accounts and, among others, works on conical pendulums, barometers and the effects of atmospheric pressure on timekeepers.

Fig. 1. Antoine Redier, 1817–1892. Bust in the Musée de l'Horlogerie at Saint-Nicolas d'Aliermont, where Redier later established a workshop with his son. The nose on the bust is damaged. It has been artificially restored on this image. By permission of the Musée.

prolific writer producing biographies, reports and articles, as well as important horological texts. His appraisals and reports for the Société were known for their clarity and fairness. Many of his biographies were published in the *Revue* and were written with a human touch. They provide us today with valuable insights into the lives and work of his contemporaries. Redier maintained a great interest in his profession, and particularly in the success of young pupils to whom he gave every encouragement.

Continuous versus intermittent action

An obvious solution to the problem of making exact measurements with a timekeeper having an intermittent action would be to use instead one that had a continuous action – such as a conical pendulum clock. In May 1860 Redier presented a *Mémoire* to the Académie des Sciences in Paris on this subject, which he later published in a more extensive form.[3] Redier's *Comparateur Chronométrique*, which is the subject of this article, is described in the *Mémoire*, but to appreciate it fully it is necessary first to examine his work with conical pendulums.

The bob of a conical pendulum follows a circular path and the pendulum from its point of suspension describes a cone. When used in a clock, impulse is given to the pendulum by contact with a rotating arm mounted beneath it, which is driven by the movement but governed in its rotation by the pendulum. There is no escapement and the action is continuous. Clocks with conical pendulums were used in connection with astronomical observations, where the events being observed were also continuous. In 1850 E.J. Dent made a chronograph for the Royal Observatory at Greenwich which was governed by a conical pendulum clock.[4]

In his *Mémoire* Redier points out that continuous action presents its own difficulties when it comes to making exact measurements. As the seconds hand sweeps continuously around the dial, it is extremely difficult to judge exactly when it falls on a particular division. However, a seconds hand that falls on a division with an accompanying 'tick', and dwells there momentarily, can be observed very accurately. Redier emphasises the importance of incorporating this feature into any device intended for precise comparisons.

Redier's 'Pendule Conique'

If a conical pendulum is used to regulate a movement that is mounted beneath it and which can be rotated relative to it, then the time shown by the hands will be either advanced or retarded depending on the direction in which the movement is turned.

3. A. Redier, *Mémoire sur le Pendule Conique et sur de Nouveaux Instruments Chronométriques auxquels il est appliqué* (Paris, 1860).

4. Vaudrey Mercer, *Edward John Dent and His Successors* (London: Antiquarian Horological Society, 1977), pp. 406–407; 428–430.

Fig. 2 (left). Redier's Comparateur à Pendule Conique, 1859. This conical pendulum clock has a mechanism that can be rotated about the axis of the pendulum, thereby altering the time shown by the hands. Fig. 3 shows the suspension in the pendule conique that enables the pendulum to follow a circular path. © Musée des arts et métiers-Cnam, Paris / Photos Michèle Favareille.

Such a clock was constructed by Redier in 1859 and is now in the Musée des Arts et Métiers, Paris (Fig. 2).[5]

The pendulum is hung from a suspension that enables it to follow a circular path (Fig. 3). In the base of the clock there are two movements (primary and secondary) mounted horizontally within a cage. Each movement has a set of hands displaying hours, minutes and seconds on the silvered dial beneath the pendulum (Figs 4 & 5). The movements are wound by means of levers that have a ratchet action and terminate with the ivory handles on either

5. Conservatoire National des Arts et Métiers, *Catalogue du Musée – Horlogerie* (Paris, 1949), Section JB3–61, Cat.no.3, pp.265–267. See also: Klaus Kölmel, 'Der Comparateur à Pendule Conique des Antoine Redier', *Klassik Uhren*, 1/2014, 26–30.

Fig. 4. The dial of the *pendule conique* and the two movements (primary and secondary) mounted beneath it form a single assembly that can be rotated relative to the pendulum. The rotating arm above the dial maintains the pendulum in motion and is driven by the primary movement. © Musée des arts et métiers-Cnam, Paris / Photo Michèle Favareille.

Fig. 5. The dial on the side of the case shows the alteration, in hundredths of a second, made to the time shown by the hands of the *pendule conique* when the mechanism is rotated. © Musée des arts et métiers-Cnam, Paris / Photo Michèle Favareille.

side. The entire assembly can be rotated relative to the pendulum by means of a crank on the right hand side of the case (not visible).

The primary movement drives a horizontal arm beneath the pendulum (Fig. 4) which engages with it and maintains it in motion, making one revolution every two seconds. The hands of the primary movement move with continuous motion. Every second the primary movement releases the secondary movement, the hands of which move in steps of one second. By rotating the assembly either to the left or to the right by means of the crank, the time shown by the hands is advanced or retarded. The adjustment made in hundredths of a second is shown on the dial on the left hand side of the case (Fig. 5). This dial has a button to enable the reading to be returned to zero after an adjustment is made. There is also a mechanism in the base of the clock for operating electrical contacts, so that a signal can be sent to a remote location.

The important feature of this clock as a *comparateur* is that it preserves the advantages of intermittent action (from the point of view of taking readings) while at the same time making it possible to synchronise the action with another timekeeper, signal or event. The disadvantage of the design is that the dial turns with the movements, making it awkward to read the hands. To overcome this, Redier describes and illustrates alternative arrangements in his *Mémoire*, where the dial is mounted on the front of the case.

Redier saw the potential for a portable device, operating on the same principle as

Fig. 6. Redier's *Comparateur Chronométrique*. It contains two movements (one in the base and one beneath the dial) that can be rotated relative to each other by turning their outer casings, thereby altering the time shown by the hands. Diameter 90 mm.

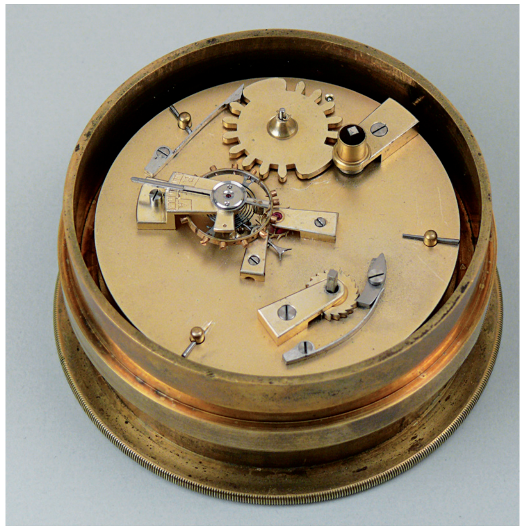

Fig. 7. The bottom drum of the *comparateur* containing the primary movement. The escape wheel is placed in the centre. Its arbor extends through the movement and carries the disc *D* shown in Fig. 8. In order to expose the movement, the knurled end cap that normally covers it has here been removed and placed beneath.

his conical pendulum clock, which he called a '*Comparateur Chronométrique*' (sometimes referred to as a *Compteur à Coïncidence*).

Redier's 'Comparateur Chronométrique'

The *comparateur* described here and shown in Fig. 6 was used in connection with geodetic surveying (that is, surveying taking into account the curvature of the earth). It is inscribed on the base '*Service Géodésique*', dated '*1879*', and is numbered '*N° 4*'. It has a velvet lined travelling case on which the inscription is repeated.[6] The *comparateur* consists of two movements, each contained within a brass drum, and mounted one above the other. The drums are held together by a brass band which enables one to be rotated relative to the other by turning their outer casings.

The bottom drum contains the primary movement which is fusee driven, with maintaining power, and is wound from the back (Fig. 7). It has a cut bimetallic balance and a ratchet tooth lever escapement. The escapement wheel is placed in the centre of the plate. It has fifteen teeth and makes one revolution in two seconds. This requires the balance to make 54,000 vibrations per hour and we shall return later to the reason for this very high rate.

The front (upper) plate of the primary movement is shown in Fig. 8. The small disc *D* in the centre is mounted on the escape wheel arbor, which extends through the plate. It carries two pins, *P1* and *P2*, and rotates once every two seconds. Also, fixed to the plate, is the wheel *W1*.

The top drum contains the secondary movement which has a going barrel. It drives the hands and is wound through the dial. The glass has a bezel with a bayonet fixing to facilitate its removal for winding. The back plate of the secondary movement is shown in Fig. 9. The arm *A* is under the power of the train and, for each revolution

6. In 1887 the Eighth Astronomer Royal, William Christie, co-operated with the French Geodetic Survey to re-determine the Greenwich-Paris baseline. See: E. Forbes, A. Meadows & D. Howse, *Greenwich Observatory* (London: Taylor & Francis, 1975), Vol. 2, p. 61.

Fig. 8. The upper plate of the primary movement. The disc *D*, carrying the pins *P1* and *P2*, is mounted on the escape wheel arbor. The pins lock the arm *A* of the secondary movement shown in Fig. 9 and the wheel *W1* engages with *W2*.

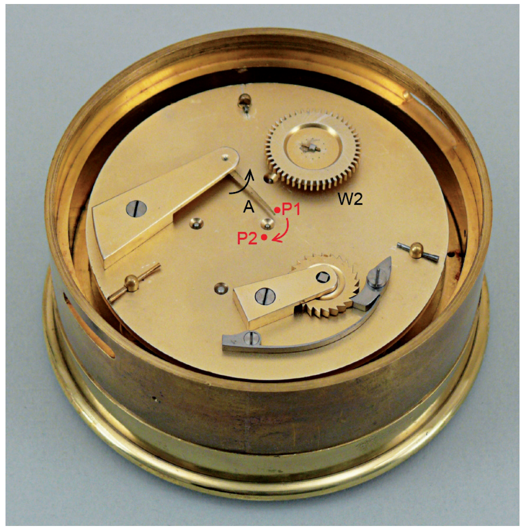

Fig. 9. The back plate of the secondary movement contained in the top drum of the *comparateur*. The arm *A* is locked by the pins *P1* and *P2* of the primary movement (which are shown superimposed in red) and the wheel *W2* engages with *W1* (Fig. 8)

that it makes, the seconds hand advances by a one second division on the dial.

When the two movements are assembled, the plates shown in Figs 8 & 9 come face to face and the pins *P1* and *P2* come into contact with the arm A. The pins are shown superimposed in red in Fig. 9. Here the arm *A* is locked against *P1* and is just about to be released as the pin moves clockwise. If no alteration is made to the relative positions of the two movements, the arm A will be released and will make one revolution in one second before it locks, with an audible 'tick', on *P2* which will by then have moved into position. However, if the bottom movement is turned in the same direction that the pins are rotating, then the arm *A* will be released a little sooner. If the bottom movement is turned in the opposite direction, the release of the arm will be delayed. The wheel *W2* drives the small hand in the top half of the dial (Fig. 10). When the movements are assembled, *W2* engages with *W1* and the hand indicates the displacement of the movements when one is turned relative to the other and, consequently, the change made to the time shown. One half revolution of the hand clockwise represents a one second advancement, and a half revolution anti-clockwise a one second delay. The graduations are in tenths of a second and are sub-divided into twentieths. As shown in Fig. 10, the relative rotation of the movements has resulted in the seconds hand being advanced by 0.3 secs. The button projecting from the case enables the indicating hand to be returned to zero after an adjustment is made.

As with the conical pendulum clock, continuous motion is the essential principle upon which the *comparateur* is based. In the case of the clock it is the motion of the pendulum that is continuous, whereas in the *comparateur* it is the disc *D* revolving. But the disc revolves through the intermittent action of a lever escapement and only if this action is extremely rapid will the turning of the disc approach continuous motion. The *comparateur* described and illustrated by Redier in his *Mémoire* has a disc with three pins that rotates once every three seconds, and the balance runs at the more moderate rate of 36,000 vibrations per hour. However, Redier states that this may be insufficient to give the degree of continuous motion required. Apparently, this proved to be the case; the

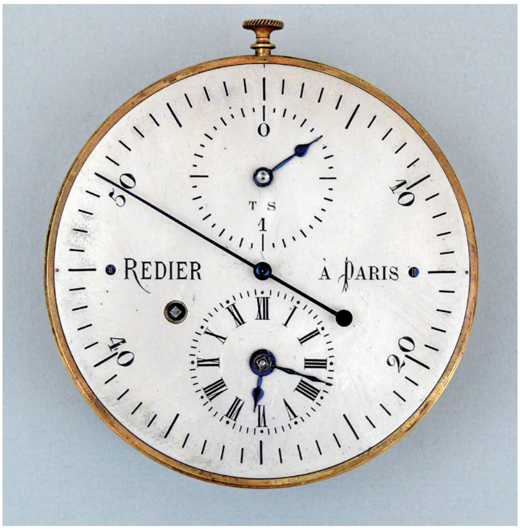

Fig. 10. The dial of the *comparateur*. The indicator in the top half of the dial registers the relative rotation of the movements. It indicates here that the seconds hand has been advanced by three tenths of a second.

example described here being constructed to operate at 54,000 vibrations per hour with the disc rotating once every two seconds.

Using the 'Comparateur'

When it is wound the *comparateur* runs continuously in the same manner as the conical pendulum clock. The hands showing hours and minutes in the lower half of the dial (Fig. 10) can be set by applying a key to the central square. The seconds hand can be brought into synchronisation with another timekeeper, or a time signal, by turning the two movements relative to each other for as many revolutions as necessary in either direction to effect the required adjustment. The indicator hand in the top half of the dial, which registers the relative rotation, can then be set to zero by pulling the button projecting from the case. Used in this way, the *comparateur* can be synchronised with a regulator, for example, and then transported to another location.

If the difference between two timekeepers is to be determined, the *comparateur* is first synchronised with one, as described above, and the indicator returned to zero. It is then brought into synchronisation with the second timekeeper by rotating the movements again. The indicator will register the adjustment made, showing the difference between the two timekeepers to a twentieth of a second.

The *comparateur* is an intriguing instrument to operate and puzzling to someone unfamiliar with it. No matter to what extent the two movements are turned relative to each other, there is no apparent change in the action of the seconds hand, which continues to advance in one second steps with an audible 'tick'. As the movements are rotated, each release of the secondary movement is altered by a fraction of a second that is too small to be observed, but these alterations accumulate the more the movements are turned. That a change has indeed taken place to the time shown, is only evident by comparison with another timekeeper or signal.

Conclusion

In 1860, at the time of its invention, Redier claimed that his *comparateur* was the first such instrument of its kind. In 1899 the English maker, George Grant, took out a patent for a means of setting the hands of a balance controlled timekeeper by rotating portion of the movement relative to the remainder.[7] A timekeeper with this feature, constructed by Grant, is described and illustrated in *The Time Museum Catalogue of Chronometers*.[8]

Grant's patent drawing is shown in Fig. 11. The balance *B*, escapement (not shown) and escape wheel *C* are mounted on the carriage *E*, which has attached to it the worm wheel *F* engaging with the worm *H*. By turning the worm the carriage is rotated about the axis *d* of the fourth wheel. Because the escape wheel is not free, its pinion *b* cannot roll around the fourth

7. George Gregor Grant, *Patent N^o 2198 – Method and Means of Setting the Hands of Balance Time-keepers* (London, 1899).

8. Anthony G. Randall, *The Time Museum Catalogue of Chronometers* (Illinois: Time Museum, 1992), Cat. no.71, pp. 181–182.

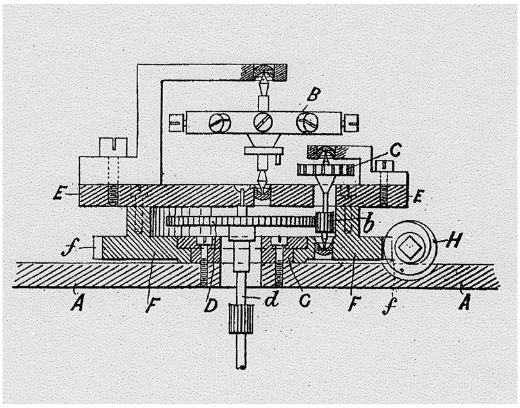

Fig. 11. Grant's patent drawing for his hand setting mechanism. The fourth wheel *D* (on the arbor of which the seconds hand is mounted) can be moved forwards or backwards by rotating the carriage *E* carrying the escapement.

wheel *D* as the carriage is turned, but instead it carries the fourth wheel with it. The principal intention is to provide a means of setting the seconds hand which is mounted on the arbor of the fourth wheel.

At first it might appear that Grant's mechanism achieves the same as Redier's – but this is not so. In Redier's device the instant that the seconds hand is released is infinitely variable, and so it can be synchronised exactly. In Grant's arrangement the instant of release cannot be altered and, although the seconds hand can be moved, it can only be adjusted as accurately as the intermittent action of the escapement will allow. Furthermore, unlike Redier's device, Grant's provides no means for making comparisons and determining differences.

Redier's *Comparateur Chronométrique* appears to be a unique invention and, apart from the example described here, the author knows of only two others. One is in the Musée des Arts et Métiers, Paris (Fig. 12)[9] and another is at the Observatoire de Paris.[10]

Fig. 12. Redier's Compteur à Coïncidence (comparateur chronométrique), 1860, in the Musée des Arts et Métiers, Paris. One of three examples that are known to the author. © Musée des arts et métiers-Cnam, Paris / Photo Michèle Favareille.

Acknowledgement

I should like to thank Anthony Randall for kindly reading the draft of my article. I am most grateful for his comments and suggestions that have helped in improving the clarity of the text.

9. Conservatoire National des Arts et Métiers, *Catalogue du Musée – Horlogerie* (Paris, 1949), Section JB3–43, Cat.no. 8, p. 232.

10. Observatoire de Paris, *Collections du Musée de l'Observatoire*, Inventory no.IA19–91.