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The Double Pendulum Clock

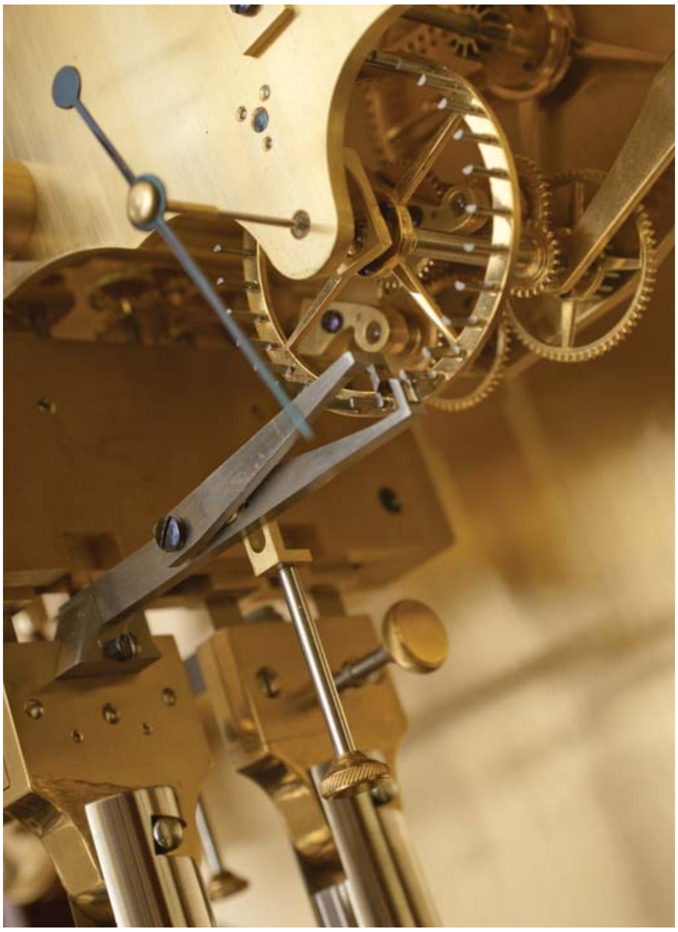
by David Walter

History

The first time I saw a photo of Breguet 3671 double pendulum clock was in 1978 when my first copy of *'The Art of Breguet'* by Dr George Daniels arrived and the book fell open at the illustration of the double pendulum clock on page 98. I studied it for hours and dreamed of the day when I too would create such an incredible clock. That day would have to wait until January 2009, when I started to work on not one, but two double pendulum clocks: one in a floor standing case with carved and gold leafed mouldings modelled on the case of Breguet 3671, and the other in a wall hanging case modelled on that of Breguet 3177, the other surviving Breguet double pendulum clock. Both cases are mahogany covered with fine crotch (flame) mahogany veneers.

One of the most impressive technical features of these double pendulum clocks is the use of resonance to lock the two pendulums in anti-phase. The amount of energy stored in an oscillating pendulum is impressive. Resonance was recognised by Galileo Galilei in 1602 in his investigations of pendulums. It occurs when two pendulums of the same frequency swing in the same plane, suspended from the same non-rigid mounting frame. Every clockmaker knows that two pendulums mounted near each other in the same plane can interfere causing one or both of them to stop. If the clock is on a soft floor, energy from the swinging pendulum can be transferred to the weight causing the clock to stop and leaving the weight swinging wildly. The classic example of the phenomenon is known as the 'Thursday effect'.

Floor standing model with the maker.



Sidereal movement escapement showing the method for attaching the pallets to the suspension.

Breguet and Janvier were aware of this and built clocks to take advantage of this resonance effect. It is necessary for the two pendulums to be identical and both very closely regulated to the same rate. Once they are set running and locked into anti-phase, each pendulum will correct errors in the other, should they occur. To fine-regulate the clock when running, small weights can be added to, or removed from, weight trays on either pendulum. In fact only one weight tray is really necessary because a weight placed on the front pendulum to increase the rate has the same and immediate effect on the rate of the rear pendulum. The rate change of the first pendulum is transferred via the suspension assembly to the second, and the two will remain in resonance at their new average frequency.

There were numerous obstacles to overcome. The lack of detailed information, as well as the realisation that the Breguet dials were so small that they are difficult to read from across a room. My first task was to draw detailed dials to the size I had decided upon (4in wide x 11in long or 120mm x 280mm). I wanted to include the Equation of Time indication which Breguet used on his right dial. However, I placed it on the left, with my right dial showing sidereal time via a special 'sidereal conversion' train that I created. The Breguet 3671 displayed mean solar time on both dials, with his right-dial seconds hand running counterclockwise.

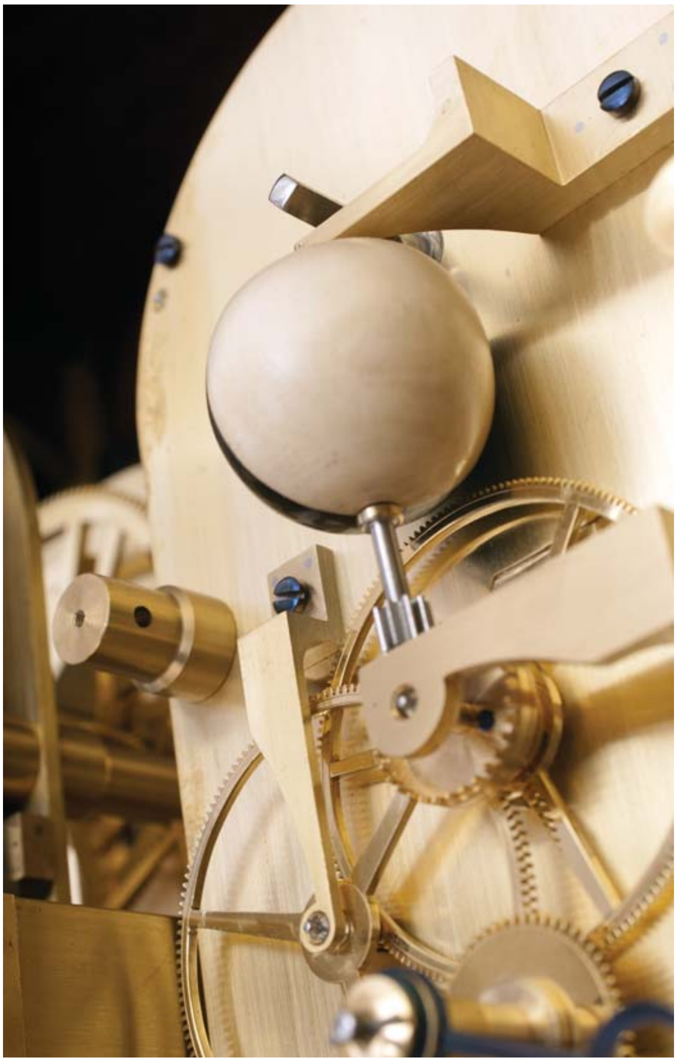
With the two pendulums in resonance they can only be regulated to the same rate. Sidereal time is a little faster than mean solar time. The sidereal seconds hand gains 1 second in about 6.1 minutes, which accumulates to the 366 days in a sidereal year.

Sidereal movement showing the lunar train.

The ‘sidereal conversion’ design, suggested by a customer, has the seconds arbor and the escape wheel co-axial, but independent of each other, and the sidereal seconds hand rotating in the conventional direction. I also included the addition of an accurate spherical Moon phase indication. All pivots were to be jewelled with endpieces where possible. The pin wheel escapements use hardened steel half pins. I chose to use half pins rather than the common round pins on the escape wheels, because half pins allow the creation of a more accurate escapement with less drop than can be achieved with full round pins, which require greater clearance for the pallet nib to clear the back portion of the pin. Finally, the pallets were to be jewelled.
The pendulum rods have been made from fused silica (quartz) tube with 9 in (230 mm) brass pendulum bobs, each of which weighs 20 lbs (9kg). To the best of my knowledge all previous double pendulum clocks relied on the pendulum support flexing enough to transfer energy between the pendulums. Breguet mentions that in order to achieve resonance he was obliged to reduce the thickness of his pendulum support. Pendulum suspensions have traditionally been made as rigid as possible to provide maximum support and to reduce the possibility of outside and undesirable vibrations having an influence on the pendulum.
After much discussion with Stephan Gagneux (maker and researcher of double pendulum clocks), I took his advice and created an unusual suspension system to support both pendulums and their pallet arms, which are fitted to the lower suspension spring blocks. The system I have built is based on having a ‘loose’ suspension, the opposite of what is normally considered desirable. Both suspension springs are fitted into a common carrier, which is gimballed to the main suspension support. This unique system has been called ‘a perfect closed feedback loop’ with very little energy loss. A good regulator pendulum mounted on a rigid support with no movement fitted and started at its operating amplitude will typically continue to oscillate for around 8 hours. My double pendulums take 21 hours to stop.
The new features are:
1. The addition of a spherical Moon phase indication. Spherical Moons present the appearance of the phases of the Moon more accurately than the traditional flat disc Moons, which are most commonly seen as they are easier to make.
2. The indication of sidereal time on the right hand dial via the sidereal conversion train.
3. Having the right hand dial’s second hand rotating clockwise. Breguet and Janvier had the seconds hand on their right-hand dials running backwards with the aim of ensuring that all forces acting on the pendulums are reversed. This reversal of convention was not necessary.
4. The movement is fully jewelled. Breguet did not fit any jewelled bearings to his clocks.
5. A special suspension to support the pendulums and improve the ‘resonance factor’.

The first double pendulum clocks were made by Janvier in the late 18th century.
In 1825, the greatest clockmaker ever, Abraham Louis Breguet, created the most elegant double pendulum clock to that date. His No. 3671 was made for George IV at a cost of £1,115 in 1825. This clock is still in possession of the British royal family. Breguet made only two other double pendulum clocks, of which one, Breguet 3177, remains, in the Musée des Arts et Métiers in Paris. The third clock was burnt in the 1871 fire that destroyed the Palais des Tuileries.
In 2002, Antiquorum sold two double pendulum clocks made by Janvier (who was a contemporary of Breguet and almost as famous). François-Paul Journe, an independent watchmaker based in Geneva who makes fine watches, bought one (1.6 million CHF), a floor standing clock. The Patek Philippe museum bought the other, a table clock (1.3 million CHF). Neither of these is as complicated as the Breguet double pendulum clocks. My goal was to equal Breguet's work and add complications to the Breguet clock upon which it is based.

Mean Solar dial with equation of time indicated by the gold hand.



Contrate drive for the spherical moon which is made of ebony and holly.

The following is a list of the thirteen known double pendulum clocks:
Abraham Louis Breguet made three clocks, only two examples remain.
Janvier made three clocks: a single-movement table clock in the Patek Philippe museum, Geneva, a double-movement floor clock in the Journe boardroom in Geneva, and a single-movement floor clock in the Musée Paul Dupuy in Toulouse.
Beat Haldimann has made two simple double pendulum clocks, one in his shop in Thun, Switzerland, and the other in the Horological Museum, La Chaux de Fonds, Switzerland.
Buchanan of Chelmsford has made one, which is in a private collection.
Stephan Gagneux of Switzerland has made one, which is in a private collection.
Florian Frisch and Claude Schauerte, students at the Swiss Watchmakers School (Bienne), made a single movement clock with the two pendulums moving fore and aft.
I have made two, both of which are in private collections in the United States.
There are no known double pendulum clocks outside of Europe and America. Of the thirteen, three are in the USA, two were made by myself. Collectors are not the only people interested in this clock – renowned horologists around the world are impressed by the results. An eminent La Chaux de Fonds horologist, reflecting on the original Breguet clocks and my DPC, said: 'It looks as though it has just left the Breguet factory!'

Double Pendulum Resonance Clock

Specifications:
Two month-running movements with separate winding for each movement.
A total of 71 jewels in both movements.
Two specially engraved dials signed, numbered and French silvered. French silvering has been an almost lost art for some time and is almost unheard of today. I was very fortunate to have a close friend who trained in France with a chronometer restorer explain to me the art of French silvering. All French marine chronometers and regulators with brass dials were silvered in the French manner which has quite a different look from English silvering and is more spectacular in appearance.
Time is indicated by blued steel hands, the left dial mean solar time hands are Breguet Moon style, while the sidereal hands are Breguet skeletonised Moon style. The Equation of Time minute hand is the unique David Walter hand, made of 14k gold.
The movements are mounted on a brass plate with provision for levelling in two planes via three brass set knobs each with locking rings. Each brass set knob screws into the massive brass mounting plate fitted to the backboard of the clock.
Weight cases, pulleys, keys, set knobs, bezels, pillars, suspension support, and the huge back plates are gold plated.
Two winding cranks are provided with each clock, one to wind both movements, and the other, smaller crank to set the hands on the left hand dial.
The Double Pendulum Resonance clock is available in a choice of either a floor standing case based on that of Breguet 3671, or a wall hanging case based on that of Breguet 3177.
Both cases are made of mahogany, veneered with fine, select crotch mahogany on the door, plinth, back and top, and additional pieces of crotch veneer applied to the plinth, door and upper case to reflect the double pendulum theme. The floor standing case, like the Breguet original, has a carved moulding around the base and three rows of carved moulding around the top covered in gold leaf.

Case dimensions:

	Floor standing clock		Wall clock	
Height:	102 in	(2.59 metres)	81 in	(2.06 metres)
Width:	29 ¼ in	(0.74 metres)	25 ¾ in	(0.65 metres)
Depth:	13 ¾ in	(0.35 metres)	14 ¾ in	(0.375 metres)

Features:
Double pendulums sharing a unique suspension support moving in resonance.
Two separate, independent movements each with a pin wheel escapement with jewelled pallets and identical seconds pendulums of fused silica with Invar fittings and compensated brass bobs.
The left movement shows:
◆ Mean and apparent solar time, with solar time indicated by a gold hand leading or following the minute hand on its path around the dial as appropriate to the time of year.
◆ Date viewed through a dial aperture.
The right movement shows:
◆ Sidereal time, indicated on a 24 hour dial in Breguet numerals, with a conversion train error of 1 second in 8.6 years.
◆ Spherical moon phase indication, with a lunar train error of 1 second in 2.6 years.
◆ With thanks to Dr J Kirk of geartrains.com for the lunar and sidereal conversion trains.

Dial Explanations:
Left hand, solar dial:
The blued steel hands indicate mean solar time, the time we

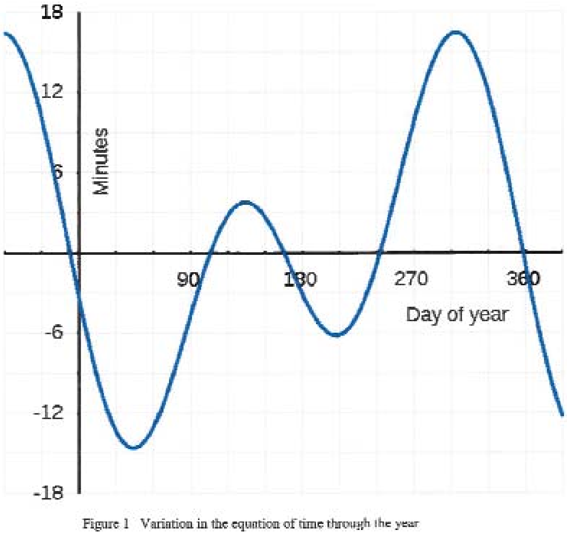


Figure 1: Variation in the equation of time through the year.

use daily. A gold hand courses around the dial with the blue steel minute hand showing apparent solar or sundial time.
The difference between the blue hand and the gold hand is the 'Equation of Time'. This time difference varies during the year from 14 minutes slow to 16 minutes fast, and is the same only four times per year.
The gold bezel surrounding this dial reminds us that this dial shows solar time.
The aperture under the bezel shows the calendar date. This calendar does NOT include a leap year day.
The hour hand is especially adjustable for easy resetting whenever daylight saving starts or ends.

Weight trays on each pendulum, the collars holding the matted brass trays are Invar.

Right hand, sidereal dial:
Sidereal time is used by astronomers because it represents the orientation of the Earth with respect to a fixed star instead of the Sun, and is always displayed on a 24 hour dial. A sidereal second is slightly shorter than a standard mean second. The actual difference is a 1 second gain in about 6.1 minutes.

Definitions:
Sidereal time as indicated on the right hand dial:
Sidereal time is the hour angle of the vernal equinox, the ascending node of the ecliptic on the celestial equator. The daily motion of this point provides a measure of the rotation of the Earth with respect to the stars, rather than the Sun. Local mean sidereal time, the sidereal time indicated on this clock, is computed from the current Greenwich Mean Sidereal Time plus an input offset in longitude (converted to a sidereal offset by the ratio 1.00273790935 of the mean solar day to the mean sidereal day). Astronomers use local sidereal time because it corresponds to the right ascension co-ordinate of a celestial body that is presently on the local meridian.
Solar time as indicated on the left hand dial.
Solar time is defined by the position of the Sun. The solar day is the time it takes for the Sun to return to the same meridian in the sky. Local apparent solar time is measured by a sundial. When the centre of the Sun is on an observer's meridian, the observer's local apparent solar time is zero hours (noon). Because the Earth moves with varying speed in its orbit at different times of the year and because the plane of the Earth's equator is inclined to its orbital plane, the length of the solar day is different depending on the time of year. It is more convenient to define time in terms of the average of local solar time. Such time, called mean solar time, may be thought of as being measured relative to an imaginary Sun (the mean Sun) that lies in the Earth's equatorial plane and about which the Earth orbits with constant speed. Every mean solar day is of the same length. The difference between the apparent solar time and the mean solar time at a given longitude is known as the equation of time.
Tables used by navigators list the equation of time for different times of year so that an observer can calculate the local mean solar time from the local apparent solar time (found by determining the Sun's hour angle). Mean solar time is the basis for standard time.
Equation of time as indicated by the gold hand on the left dial.
The equation of time is the local apparent solar time minus local mean solar time, both taken at a given place (or at another place with the same geographical longitude) at the same instant of time.

Fused Silica pendulum rods entering the two piece brass pendulum bobs.

Date aperture in the French silvered mean solar dial, the shaft above the date is for setting the hands using a special key.

Gold plated key and tassel for the door locks.

Hand engraved signature on the mean solar dial.

Apparent (or true) solar time can be obtained, for example, by measurement of the current position (hour angle) of the Sun, or indicated (with limited accuracy) by a sundial. Mean solar time, for the same place, would be the time indicated by a steady clock set so that its differences over the year from apparent solar time average to zero (with zero net gain or loss over the year).

The equation of time varies over the course of a year in a way that is almost exactly reproduced from one year to the next. Apparent time, and the sundial, can be ahead (fast) by as much as 16 min 33 s (around 3 November), or behind (slow) by as much as 14 min 6 s (around 12 February).

The equation of time results mainly from two different superposed astronomical causes (explained below), each causing a different non-uniformity in the apparent daily motion of the Sun relative to the stars, and contributing a part of the effect:

- The obliquity of the ecliptic (the plane of the Earth's annual orbital motion around the Sun), which is inclined by about 23.44 degrees relative to the plane of the Earth's equator and
- The eccentricity and elliptical form of the Earth's orbit around the Sun.

The equation of time is also the east or west component of the analemma, a curve representing the angular offset of the Sun from its mean position on the celestial sphere as viewed from Earth.

The equation of time was used historically to set clocks. Between the invention of accurate clocks in 1656 and the advent of commercial time distribution services around 1900, one of two common land-based ways to set clocks was by observing the passage of the Sun across the local meridian at noon. The moment the Sun passed overhead, the clock was set to noon, offset by the number of minutes given by the equation of time for that date. (The second method did not use the equation of time; it used stellar observations to give sidereal time, in combination with the relation between sidereal time and solar time.) The equation of time values for each day of the year, compiled by astronomical observatories, were widely listed in almanacs and ephemerides.

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Pictures by Bill Taylor ASC, HonFBHI