Double Pendulum
Resonance Clocks

John Kirk
Topics

• Introduction
• Resonance
• Early Makers
• Janvier’s Clocks
• Breguet’s Clocks
• Modern Clocks
• “Reproductions”
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Introduction

• While there are three and four pendulum clocks, most multi-pendulum clocks have two pendulums
  – Clocks with more than two pendulums will be the subject of another presentation

• Resonance clocks have two or more pendulums locked to each other in rate, which aids rate stability and can compensate for disturbances
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Resonance (1 of 4)

• Two mechanical oscillators, such as balance wheels or pendulums, can influence each to become resonant

• For this to happen,
  – The oscillation of one must be detected mechanically by the other, such as two pendulums on a common slightly soft mounting
  – The two oscillators must have close to the same period of oscillation
Resonance (2 of 4)

• When two pendulums influence each other of almost the same frequency, the two will trade energy until they swing in anti-phase.

• This occurs because swinging in anti-phase has the lowest system energy level.
  – All resonant systems “relax” total system energy to the lowest level.
  – This lowest level also requires the least energy to keep both oscillators in the system oscillating.
The “Thursday Mystery” is well-known among repairers of tall-case clocks

- The owner complains that his clock always stops on Thursdays, but isn’t run down
- If he watched it happen, he will say that the drive weight started swinging on its rope or chain, and swung more and more wildly while the pendulum swung in smaller and smaller arcs until it stopped

What happened, and why?
Resonance (4 of 4)

• At the time the trouble began, the length of the weight rope or chain was about the same as the pendulum rod, and the two had nearly the same period.

• The pendulum, swinging back and forth rocked the case from side to side.
  – It was on a “soft” floor, such as thick carpet, or was otherwise free to move from side to side.

• Energy from the swinging pendulum was transferred to the swinging weight at the expense of its amplitude until the pendulum could no longer unlock the escapement.
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Early Makers

• Daniel Quare (1648 – 1724)
  – His *Dictionary of National Biography* entry states that “There is ... at the Royal Hospital, Greenwich, a very curious clock by Quare with a double pendulum.”
  * This is indeed a double pendulum clock, with two separate movements. However, the movements run at mean solar and sidereal rates, which are different enough in period (~.3%) that they wouldn’t lock up given reasonably stiff suspension supports

• William Scafe (1687 - ca. 1764)
Scafe (1 of 3)

• This ~ 11 ft tall clock (~1740/1750) has an unusual dial and movement
  – The lower half of the dial is marked 1-11 for hours, with the 12 in its usual place at the top
  – The hour hand moves at “normal” speed from 1 -11, the bottom half of the dial
  – Between 11 and 1 it moves across the top half of the dial
Scafe (2 of 3)

- The hour and minute hands cannot be adjusted; one must stop the clock then restart it at the correct time.
- There is a sliding rise/fall regulation cage for two pendulums on one escapement with a double crutchpiece.
Scafe (3 of 3)

• It appears that the two pendulums are not mounted at the same height
  – This shouldn’t affect resonance operation

• Precisely how the escapement works isn’t clear...
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Janvier (1 of 5)

- This is probably Janvier’s first double pendulum clock, sold in 1804
- It has only one movement, but two escapements, each with one pallet attached to one pendulum
- The two escape wheels are on the same arbor, so the two pendulums must be in perfect synchronism for the clock to run
- In starting the clock, if neither pallet is in contact with its escape wheel, the movement would run freely at high speed, likely to disaster
Janvier (2 of 5)

• This gorgeous double pendulum clock by Janvier has two complete movements, both indicating civil time

• The pendulums run in anti-phase resonance

• The circular disk in the middle is the driving weight, suspended by cords around each movement’s barrel

• The compensators are just above the pendulum bobs
The dials are not identical
• Note the numbering on the two seconds dials; the hand on the right movement turns counterclockwise, as does that in the dial above it.

• The right-hand movement is likely a mirror image of the left, but without the hour wheel.
• This fascinating mantel clock has an unusual escapement
• The impulses are applied to the free ends of the pendulums below the bobs
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This double pendulum clock was sold to Louis XVIII of France in 1821, and is currently in Musée des arts et métiers in Paris.

The movements and pendulums are mounted on a massive backboard, with the common driving weight down in front.

The front of the case lifts off, and is likely both heavy and awkward.

- Fortunately, there are two holes in the front glass, one for each movement, for the winding key.
Breguet No. 3177 (2 of 2)

- The movements are identical, with Graham deadbeat escapements at the top
- Presumably, there are conventional crutches to the two gridiron pendulum, but I couldn’t see them when I visited the Musée des arts et métiers to look at this clock
- Note the lovely French silver dials
Breguet No. 3671 (1 of 6)

- This marvelous clock by The Master was sold in 1825, after Breguet’s death to King George IV and remains in the Royal Collection
- Like the second Janvier, there are two movements driving the seconds hands in opposite directions, clockwise on the left
- Note the triple-stacked gridirons
- This clock was fabricated for Breguet by Bourdier
Breguet No. 3671 (2 of 6)

- The two movements are dissimilar, though both show civil time
- The left dial has the hour display in the window, with minutes and seconds on separate dials
- The right movement has a conventional time display, plus a minute hand for apparent solar time and the date on the equation-of-time cam arbor
Breguet No. 3671 (3 of 6)

- In this view, the massive backplate and pendulums support plate and tongue are clearly visible.
- The movements have pinwheel escapements, with pallets attached to the lower suspension spring clamps.
- The rectangular structure with plinth below the backplate is the stack for a charcoal furnace in the bottom of the case to warm it in very cold weather.
Breguet No. 3671 (4 of 6)

- Another view of the dials
- The Equation of Time mechanism is mounted on the back of the right dial
  - Note that the right dial has a variety of pivot tips and holes in it
  - There are no jeweled arbors in this clock
- The right dial second hand runs counterclockwise
Breguet No. 3671 (5 of 6)

• This is the back of the right movement dial
• Note the Equation of Time cam and pivoted follower, with the other end near the wheel on the lower end of the V-block
• This is the underside of the V-block, with the sensing finger for the apparent solar time minute hand position

• Each hour the outstretched finger is set by brushing the upper end of the cam lever, and the balanced racks set the apparent time minute hand
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Stephan Gagneux, a retired Swiss physicist, became interested in resonance

– He designed and built test rigs to determine and optimize the conditions for achieving it in clocks

– A joint effort of Stephan Gagneux and Beat Haldimann led to this clock shown at BaselWorld 2000
• This spare clock has two civil movements
• The two pendulums swing fore and aft, in resonance, in a partially evacuated glass case
  – It makes the clock look as if it’s walking towards you
• The suspension design assures that the pendulums affect each other equally
  – In the Gagneux-Haldimann clock, the front pendulum is less rigidly attached and thus more strongly affected by the resonance than the rear pendulum
Gagneux (2 of 2)

- The movements impulse the pendulums by strong magnets
- A series of levers in ball races convert the pallets’ side-to-side rocking to the magnets’ fore-and-aft rocking
- Damned clever
Haldimann

- Beat Haldimann made this clock for and it is displayed in the Musée international d'horlogerie, La Chaux-de-Fonds, Switzerland
- It shows local time at Greenwich on a 24-hour dial (UTC) and local time at La Chaux-de-Fonds, Switzerland on a 12-hour dial
Frisch & Shauerte (1 of 3)

- Made by Florian Frisch and Claude Schauerte, students at the Swiss Watchmakers School (Bienne)
- Two pendulums swinging fore and aft, with one movement
  - They claimed that a single movement with two pendulums in resonance is unique, apparently unaware of Janvier’s work (slide 16)
Frisch & Shauerte (2 of 3)

• The carbon fiber covered backboard was made by a snowboard manufacturer
  – It carries a marble block with a brass plate to which the pendulum mounting and movement are attached

• The pendulum rods are carbon fiber
  – They acknowledge that carbon fiber is unproven compared to Invar, but “wanted to build a unique 21st century clock”

• Wires for the two weights come off the top (left) and bottom (right) of a single barrel
The drawing shows the escapement from the back looking forward.

The deadbeat escapement anchor rocks a horizontal crutch $AB$ that impulses the pendulums $LM$ through the balls $JK$.

$AB$ is in two hinged sections, aligned by the spring $E$, also rocked by the anchor, so that the pendulums can be driven independently.

Screws $FG$ adjust the degree of linkage between the pendulums.
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Blake (1 of 2)

- This copy of Breguet 3671 was made by Maurice Blake, an Irish engineer and amateur horologist, in the 1980s
- He apparently made a series (at least five!) of these, running for one, three, or twelve months
- Pendulums are steel/zinc compensated, 20 lbs. each, both driven by a common 11 lb. weight (for which duration not stated)
- In his first clock the mounting was so rigid that he had to slit the support a bit with a saw to achieve resonance, and later discovered that Breguet had also done this
Blake (2 of 2)

- Pinwheel escapements, usually
- Dials show the usual hours, minutes, seconds, though some have “lunar, solar, and equation of time trains”
- Data from a report of AHS Irish Section 12/2/1986 meeting in *Antiquarian Horology*, March 1987, pp. 488-489
Noakes (1 of 6)

• Made by Deryck Noakes and his father DBA Buchanan of Chelmsford
  – They moved from South Africa to England in 1999, but have since moved on to Australia

• This clock is described by its owner as “an *hommage* to Breguet”
  – The dials, movements’ backplate, and driving weight certainly follow Breguet’s 3671
  – The wall-hanging case seems closer to Janvier’s floor-standing double-movement clock
Noakes (2 of 6)

- The two dials resemble Breguet’s No. 3671, but are swapped left for right
- The left clock display and movement, except the escapement, are like Breguet’s
Noakes (3 of 6)

• On the right movement, the top and middle dials display sidereal time, though the hours window runs only from I to XII
  – Sidereal time is always reckoned on a 24$^\text{h}$ scale in Arabic numerals; it has no “am” or “pm”

• The seconds hand displays civil, not sidereal, seconds
  – Sidereal time gains 3$^\text{m}$ 56$^\text{s}$ per day, or a second about every 6$^\text{m}$ on mean solar time
Noakes (4 of 6)

- The drawing shows that Noakes generally followed Breguet’s design for the Equation of Time / apparent solar time mechanism
  - See slide 28
Noakes (5 of 6)

- This is a drawing of the escapement
  - There are both pin and toothed escape wheels, with a remontoire spring in between
  - This is a gravity escapement, $A$ is the gravity arm, which drops and rolls on the arm $G$ attached to the pendulum for each impulse
  - Each pendulum rides on a knife edge
Noakes (6 of 6)

• The escape arbors are each suspended by anti-friction wheels

• This clock is spectacular, but has challenges
  – Dirt can get under the knife edges easily
  – Dirt can settle on the anti-friction wheels
  – There are an awful lot of delicate parts to become disarranged

• Unlike the Noakes’ customer, Breguet believed in elegance and simplicity
David Walter (1 of 11)

- This gorgeous clock is David’s Dual Pendulum Resonance Clock No. 1
- The case is a scaled-up version of Breguet 3671 (see slide 24)
- Unlike Breguet’s clocks, which had no jeweled arbors, all arbors are jeweled, including the barrels
  - Both movements together contain 71 jewels, including four on the escape pallets
The dials are also scaled-up from Breguet’s, and

- Breguet’s mean and apparent solar display moved from the right to the left side, with the seconds hand turning clockwise.

- A sidereal time and spherical lunar phase display on the right, with both the escape wheel and the sidereal seconds hand turning clockwise.
The LH dial shows mean solar time (blued hands) with apparent solar minutes (golden hand)

The aperture just below the dial shows (simple) calendar date, on the equation-of-time cam arbor
• The RH dial shows sidereal time and the Moon phase

• This display required a sidereal conversion gear train and a lunar display train for 29.61... sidereal days rather than 29.53... mean solar days in a synodic month
The solar escapement is on the left and the sidereal on the right.

Both escape wheels turn clockwise.

- Breguet’s, Janvier’s, and the Noakes’ RH escape pinwheels turned backwards.
- David found that pallets on the RH pinwheel needed to be shaped differently from those on the LH pinwheel.
• This is the sidereal movement escape wheel on a pipe
  – It turns at solar rate of one turn per minute
• The sidereal conversion train is below it, driving the seconds arbor through the pipe at sidereal rate
• Sidereal side escape wheel with pipe, pallets, sidereal conversion train, and coaxial sidereal seconds arbor
• This movie shows the escapements in action
• They are fascinating to watch
This is DPC No. 0P, the prototype

It is mechanically identical to DPC No. 1, which was actually finished first

The case was inspired by Breguet’s 3177 (see slide 22)

It has a conventional door rather than a lift-off front on a massive fixed backboard
• I claim that this is the best-dressed living room wall in Santa Barbara

• The clock on the left is David’s Vienna Transition No. 1, which he made for me in the late 1990s

• For scale, the top of my head is at the level of the center of VT1’s dial
David Walter (Providing Scale)