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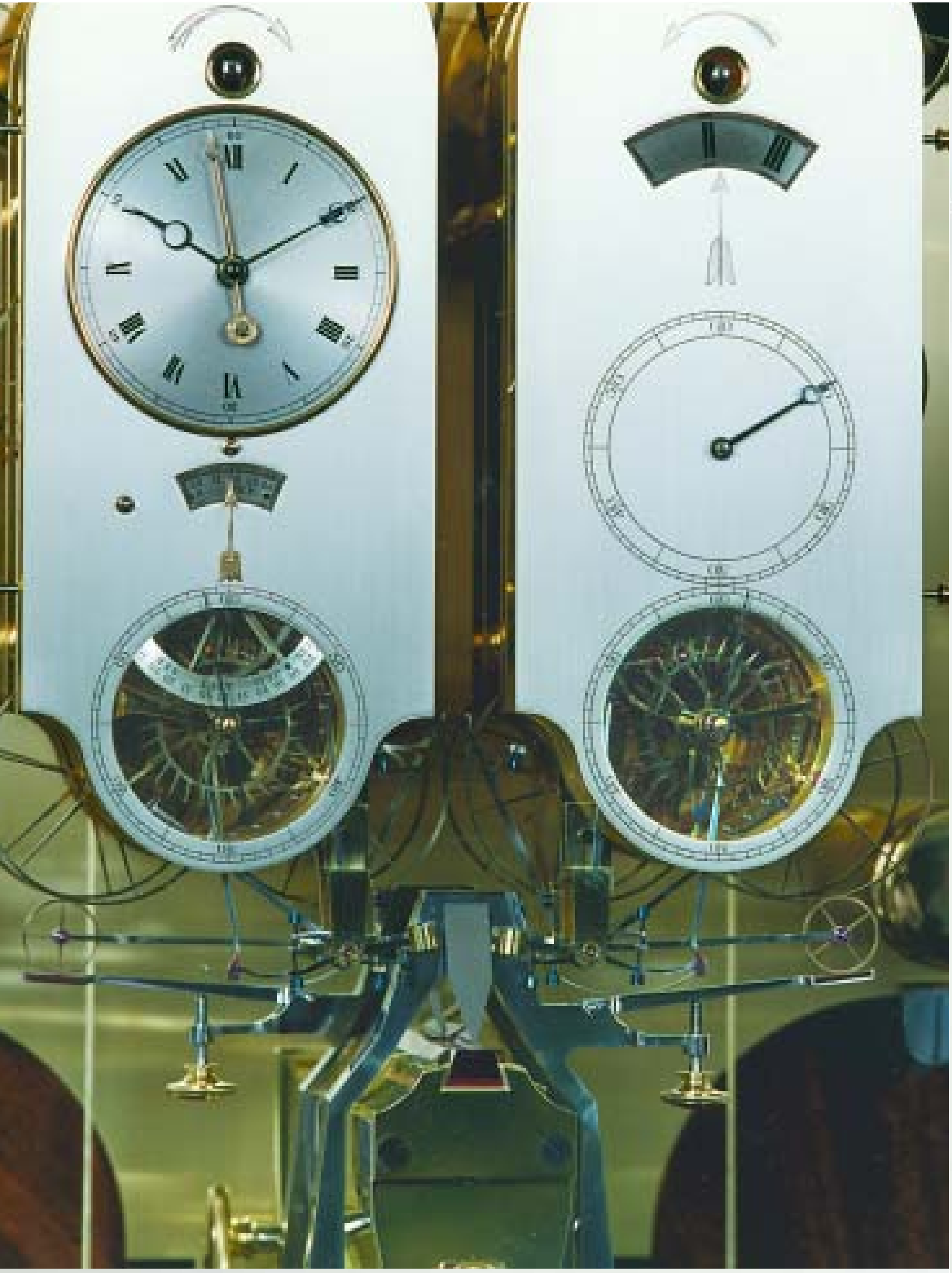


50
Froid
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The BUCHANAN Twin Pendulum Clock

Peter Powell describes Buchanan No. 4: an ‘Hommage’ to Breguet

ABRAHAM LOUIS BREGUET, 1747-1823, is described by Britten in: *Old Clocks and Watches and their Makers*, as ‘…the predominant continental horologist of his period. …The intense and abiding interest taken [in his work] ... may be traced to the great variety of his conceptions and the exactness with which they were carried out. He had the faculty of surrounding himself with assistants who were good mechanicians and able to embody his ideas to the best advantage.’

Given this level of fame it is less than surprising that it had become the ambition of an avid American collector to own a clock which was, as he put it ‘an *hommage* (he used the French pronunciation) to Breguet.’

Rather than set out to buy a Breguet, or possibly a Janvier, the collector – I am asked not to use his name so this is all I may call him – had set his heart upon having a clock made which reflected all that he saw as the best of the late 18th century. And it was by chance, pure chance, that he met a small and dedicated team of clockmakers who trade as BUCHANAN OF CHELMSFORD.

The business started in South Africa as a local father-and-son clock and watch repair business and developed into precision engineering, making, *inter alia*, dies for plastic injection-moulding machines. The move to England, in 1999, saw the appearance of its masterpiece – BUCHANAN No. 1 – as reported in the *HJ*, October 2003. Very much in the tradition of the horological ‘Master Piece’ this was a demonstration not just of what could be achieved but the artistry that could be included in the making.

Two commissions followed which, with the firm’s precision engineering work, kept its small workshop busy. When the American customer appeared asking for a precision clock, to include elements of the ideas of Janvier, Harrison and Breguet, amongst others, BUCHANAN were more than interested.

Design

Rather than create a set of definitive plans for the clock, its basic design evolved over a number of meetings, discussions, and visits to significant clocks of the period. However the customer already had clear ideas on a number of points – he wanted twin movements – one for mean and solar time and the other to show sidereal – each with its own, separate, pendulum, but with the pair synchronised by the resonance between their pendulums[1]. As this matched closely with the clock (No. 3671)[2] Breguet made for King George IV, which is now in the Queen’s Collection in Buckingham Palace, other requirements were quickly established: that the clock be wall-hanging; that the case should have a minimal frame and a maximal area of glass, and that it should be complex and eye-catching with as many visible moving parts as possible. The result is depicted on the covers of this issue.

As this was to be a precision time-piece it was to have anti-friction wheels throughout the going train, with these and other arbors running in jewels.

As an *hommage* to Breguet the customer was keen to see the dials laid out in a manner similar to No. 3671, except that he preferred the equation dial to be on the left, rather than on the right as it is in the Queen’s clock. That exception aside the dials follow the Breguet pattern with the upper dial, showing mean time with solar minutes on a solid gold hand. There is a calendar aperture below and an anti-clockwise-running seconds dial at the bottom, **1**. The second movement carries an hours aperture at the top with sidereal minutes on a central dial and seconds running conventionally at the bottom. So that the seconds hand will align with the appropriate dial marks, and to avoid the need for a further 60:1 step-up in the sidereal train, it shows mean solar, rather than sidereal time. Very much in the tradition of the better clocks of the 1800s the dials are made from solid silver, some 3 mm thick, appropriately engraved. An optional second set of

1. Ivar Peterson: *Staying in Step*: www.maa.org/mathland/mathtrek-10-9-00.html
2. Derek Roberts: *Precision Pendulum Clocks* (Volume III), p.56

HARRIER PRODUCTIONS

1. ‘BUCHANAN No.4’. The pendulums are removed showing the ‘yo-yo’ weight which drives both movements. The dial on the left (for detail see rear cover) shows mean time with solar time, calendar and seconds (anticlockwise). The right hand dial shows sidereal time, hours, minutes and seconds (clockwise).

dials has also been created, these of glass, the better to show off the complexities and the motions of the movements.

Following the structure used by Breguet both movements use a four-plate pillared construction (**front cover**). The front three plates are 4 mm thick and the rear plate, and its half-plate extension, are 4.5 mm, the better to support the four pillars and the combined weight of the movements and the 15 kg yo-yo weight, **1**. The outer pair of plates carry the anti-friction wheels running in jewelled chatons secured together by shouldered, blued steel screws such that they can be retained as pairs, without disturbing the anti-friction wheels, when the bolts are unscrewed from the four central pillars to enable access to the trains. The main clock train runs between the inner plates with the centre arbor including an anti-backlash coupling to enable the upper cartridge to be separated easily from the under-dial work.

At its top the rearmost plate includes a pillared extension to accommodate the greater lengths of the winding arbors with their barrels and sun-and-planet 3:1 reduction, which also provides maintaining power. Stop work is fitted to both winding barrels to ensure that both can be fully wound without risk.

The four arbors of the main trains are supported by pairs of anti-friction wheels set such that their contact angle with the arbors is approximately 90°. The anti-friction wheels are sized in proportion to the loads they carry, those at the top of the train, supporting the winding arbor are the most substantial and are of the order of 65 mm in diameter, 1.5 mm thick with 8 crossings and rims of some 2 mm depth. Further down the train six crossings are used, diameters reduce to around 55 mm and thicknesses come down progressively to 0.6 mm with rims of 1 mm.

The clearance holes in the inner plates, through which the train arbors pass, are sized so that irrespective of how the movements might be oriented during transport, assembly, or later servicing, it is not possible for any part of the train to fall out of mesh. This has also made the assembly process considerably less risky as it reduces the chance that wheels and pinions might be damaged.

Due to the indeterminate nature of the forces that can be applied during winding, both ends of the barrel arbor are supported on three anti-friction wheels. Single wheels are positioned below the arbors to support the load of the driving weight and pairs are set above to ensure that the arbor cannot lift out of mesh with the consequent potential for considerable damage should the clock be powered. The jewels supporting these anti-friction arbors are proportionately substantial; the rear jewel, which carries the majority of the load of the going weight, is some 5 mm in diameter, 3 mm deep and is drilled for a 2 mm pivot, the front jewel is similar diameter but a little shorter with a depth of 2 mm.

As the going trains are identical, and run on one-second pendulums – albeit only impulsed every second second, under-dial work is required to achieve a true sidereal indication on the second movement.

Main Clock Train (both movements)

Great Wheel 160, Intermediate 154 (pinion 16), Hour 135 (16), Minute 152 (18), Escape/seconds 180 (19), Fly 12

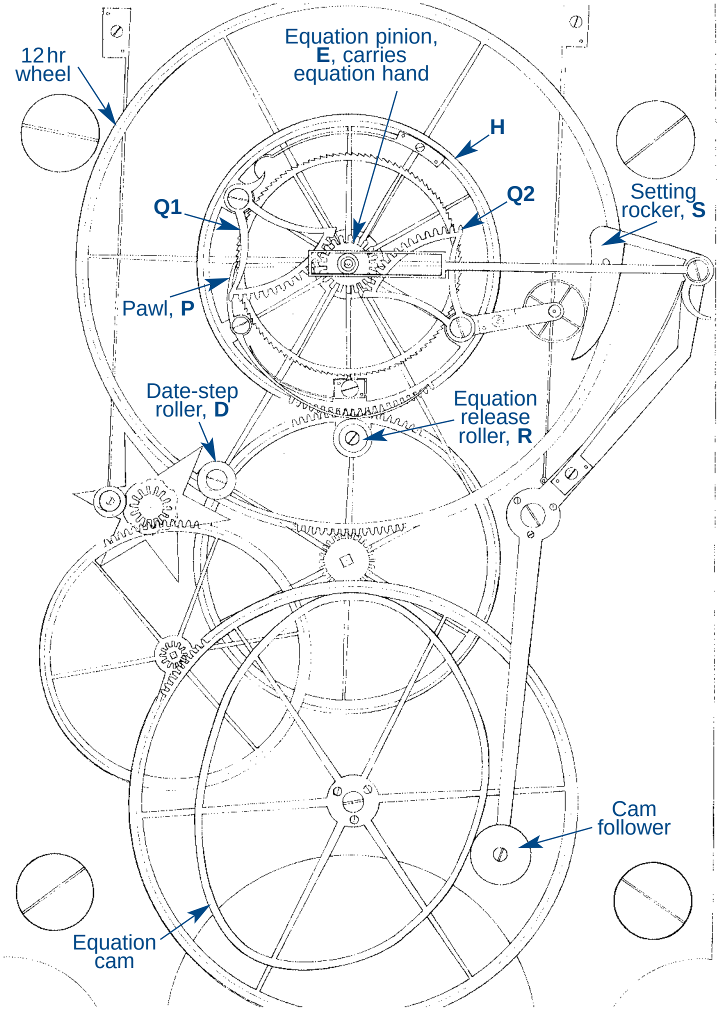
Mean Solar/Sidereal Conversion Train

87 (37), 82 (31), 97 (49), 47 (15). The train chosen here, which is taken directly from the work of David Carpenter[3], gives an error of 0.0073 seconds a year and is the most accurate 4-train sequence he devised with prime-number tooth-counts under 100.

Equation of Time

Conversion from solar mean time to true solar time is via a conventional kidney cam. As in Breguet's clock the correction is sampled once an hour and the offset left locked, with no force or drag on the kidney cam, until the next sample is taken.

3. David Carpenter: 'Calculating and Implementing Astronomical Gear Trains', *HJ*, **137**, p.274 (August) 1995.



2. The mechanism for the solar time display (see text) provides an example of the complexity of this clock.

The mechanism, **2**, is based on a pair of quadrants, Q1, Q2, mounted within the hour wheel, H, which offset the equation pinion, E, on which is mounted the equation hand, in solid gold. The offset this achieves is frozen by a long-tailed pawl, P, which locks in the finely-toothed rim of the equation wheel and is released when the tail of the pawl arm contacts the release roller, R, on the adjacent intermediate wheel, to which it is geared 1:1. When the pawl is released, the spring bearing on the anti-backlash quadrant, Q1, tries to rotate the equation pinion anti-clockwise but is controlled by its twin, Q2, and its contact with the rocker, S, pivoted onto the equation cam. As the equation release roller is small, and as it and the tail of the pawl are both mounted on the periphery of adjacent wheels, contact friction is minimal and contact time is short, probably about a minute. This arrangement has the advantage that the relationship between the two can be varied with precision by moving one wheel relative to the other a tooth at a time.

The date-step roller, D, on the 12-hour wheel indexes a star-wheel twice per day, which, through a train of (6/15) x (100/12) x 219 ensures that the kidney cam rotates once per year.

Escapement

The escapement is the jewel in this particular crown. While it includes hints of Harrison it is uniquely Buchanan. At first sight it appears rather complex – very much to the customer's liking. However, when it is seen as two separate escapements; one regulating the clock, which has a two-second beat; and the other simply providing a one-second output for the seconds hand, it becomes more understandable.

As shown in, **3**, two escape wheels (P and E) are mounted concentrically – the rearmost, P, carries 30 pins and is locked by the fly pinion, F. When the fly pinion is released the pin wheel rotates and the lifting arm, A, is raised which, in turn, lifts the

Drawings: Buchanan / Photographs: Peter Powell gravity arm, A•, of which it is part. The gravity arm remains in this position, locked by the fly arbor, until it is lifted by the jewelled plate on the pendulum arm, G, as the pendulum swings to the right. The nags head, A••, then drops away from the pin on which it has rested, and clears the pin-wheel, P, ready for its next step. The considerable damping effect of the fly ensures that the locking force – and hence the unlocking force, of the escapement, are minimal.

As the pendulum moves away and the gravity arm, G, drops, it depresses locking arm, B, which releases the fly, F, and so releases the pin wheel allowing it to return the locking arm and the gravity arm to their cocked position. The release point of the fly locking arm is set such that its freedom is only momentary and that, by the time it has rotated through 180°, damped as it is by its own fly, the locking detent, B, has returned to its lock position.

As can be seen in, **4**, the toothed escape wheel, E, lies on the same axis as the pin wheel, P, however their arbors are separate and the only linkage between them is a pre-loaded helical spring which is wound every two seconds as the pin wheel advances.

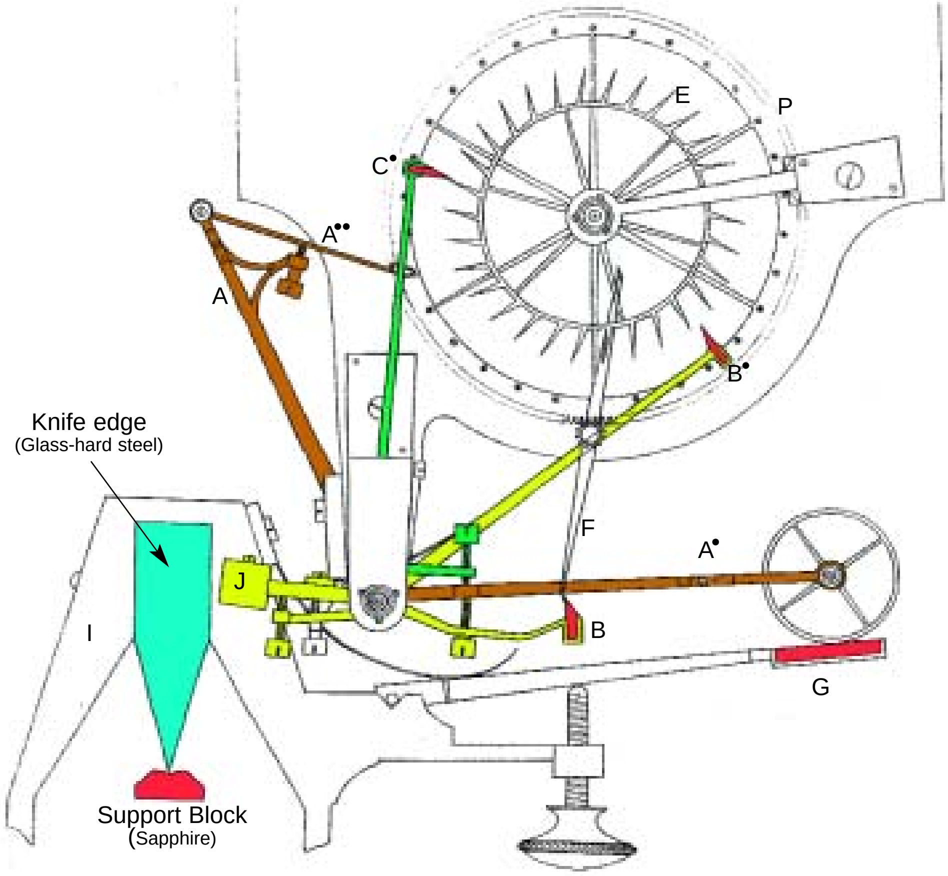
The gentle torque provided by the spring is recharged by 12° every second second and released by 6° every second, an arrangement, not dissimilar to a remontoir, which again achieves very light locking and unlocking forces. Release, and consequent movement of the toothed pin wheel, occurs as the fly locking arm moves down to release the fly, so driving down the counter-balanced locking pallet, J-B•.

Located on the opposite side of the toothed escape wheel, E, pallet, C•, is already in position to lock the escape wheel half a tooth later. The release of C• occurs as the gravity arm, A•, is raised by rotation of the pin wheel. The exact positions of the twin releases of the toothed escape wheel can be adjusted through the setting screws to achieve a regular, one-second, movement of the seconds hand, which is fitted directly onto the seconds escape wheel arbor.

The escapement is designed for a pendulum arc of 2°, in operation, with supplementary arc, it settles to around 2.5°.

Pendulum

The twin pendulums are near identical in design, differing only in that the front one includes a thermometer in its boss (**rear cover**), the mass of which has been allowed for in the machining of the solid brass body of the pendulum. The thermometer is unique in that it includes the one element of the whole clock that has not been made by, or under the direction of, BUCHANAN; a fusee chain. Otherwise it is



3. Principle of the escapement. Continuity of levers as indicated. For explanation see text.

*4. Detail of the escapement viewed from below. The arbor of the pin-wheel, **P** (see also **3**) is aligned with that of the escape wheel to which it is linked by the spiral spring. This assembly provides dead seconds although the movements impulse on alternate beats of the pendulums.*

relatively conventional, the twin rings of the thermal band were turned out of solid brass and steel respectively, drilled and tapped and then split to provide the input to the rack and rack-wheel which drive the single blued hand. In keeping with the main movements, the thermometer dial is solid silver, 1.5 mm thick.

Following the pattern set by Breguet the pendulums use nine rods each, five of steel and four of brass, supported by clamping brackets and terminating in top and bottom steel end plates, **5**. The steel rods are bolted directly to the bottom and top plates with the latter including pivot pins to allow for any slight difference in expansion. The brass rods (always in compression) are simply retained by the end plates and constrained by the clamping brackets. The rods themselves are of an oval form favoured by French clockmakers towards the end of the 18th century for aerodynamic reasons.

The central steel rod is squared through the bottom block which is supported on an engraved rating nut, **5**, set on a thread of some 80 tpi, giving it an adjustment of ca. 15 seconds per day per turn.

Both pendulums are suspended on glass-hard carbon steel knife edges to which they are linked by suspension stirrups, **6**. The knife edge is set on a central pivot pin to allow for minor discrepancies of the back plate from the vertical. Each frame carries a lateral impulse arm, with a synthetic ruby plate at its extremity, which makes contact with the roller of the gravity arm every two seconds.

Jewels

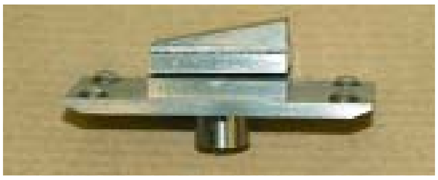
All the jewels used in the clock were cut from synthetic ruby, a coloured form of sapphire (chemically corundum, a pure oxide of aluminium), with a Mohr hardness of 9 (diamond is 10). While smaller elements were cut from material that started life as fashion jewellery, other elements, in particular the flat bearing plates for the gravity wheels and the platforms on which the knife-edges bear, were cut direct from a boule, **8**. All the cutting was done using fine copper disks loaded with diamond grit, and copper disks, similarly loaded, were used to polish the finished elements. The circular jewels used as bearings for the anti-friction wheels are mounted in chatons which are each retained in the clock plates by three small screws, some as small as 0.5 mm, and with a pitch of 0.125 mm; a classic technique in fine watchmaking.

Weight

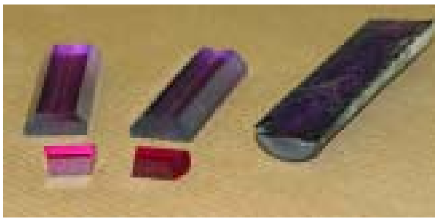
While twin weights could have been used, and have possibly trebled the one-month duration of the clocks, the single ‘yo-yo’ shape straddling the line, **1**, and the short drop, were chosen in deference to Breguet. Five parts, plus a filling of tungsten (some 70% denser than lead), make up a total mass of 15 kg which is supported by a 3 metres of 1.8 mm gut line, made for Buchanan by a company which normally produces strings for harps.

5. Detail of some of the upper and lower components of one of the brass and steel grid-iron pendulums.

6. The polished steel pendulum suspension stirrup with its hardened steel knife edge and adjustable lateral ruby pallet (arrow) to receive impulse.



*7. This wedge assembly can be raised and lowered beneath the pendulum stirrups lifting the knife edges and clamping the pendulums if required. The spheres and sockets (**6**) ensure that the knife edges are correctly aligned when brought back into use.*



8. Jewels are cut from a synthetic sapphire boule (right). Centre and left are the support jewels and end stops for the knife edge support platform.

Suspension

Key to the harmonic motion[2], and the transfer of energy between the twin pendulums, the central support block is considerably more complex than it might appear. Some 80 parts together provide independent lateral adjustment of the support trays and adjustment of the pair forwards and backwards under the control of four adjuster wheels; two on a common arbor and two operating independently.

On its top surface the block carries two ruby platforms, **8**, providing bearing surfaces for the knife-edges. Each has a small, flat-bottomed slot to restrain the knife-edges should they be displaced laterally. The ends of the knife-edges are shaped so that no more than point contact can be made with the end stops to the slots, **8**.

Beneath the support block a single clamp plate enables the pendulum stirrups to be clamped securely with their knife-edges clear of their ruby bearing plates. Designed with sufficient strength to be able to support both pendulums, it also serves to provide accurate location of the knife-edges as they are lowered from their lock into their working positions.

As the support block is the essential element in the communication between the motion of two pendulums it has to be sufficiently rigid to not absorb energy of itself while still being able to conduct sufficient movement to enable shared harmonic motion. Early tests showed that a single pendulum created a lateral movement of about 15 microns at the support and that, with both pendulums set to the same rate, and with one stopped, it would gain sufficient impetus to restart its movement in about an hour.

The support block and the two movements are mounted directly to a massive mounting-plate, this is of brass some 320 mm wide by 450 high and 18 thick. This carries four tapered mounts, **9**, (two for each movement) to which the movements are secured by clamp screws, **10**, which also serve to aid the release of the tapers. In turn four brass-capped bolts clamp the back plate, though the back board of the case, to a 20 mm steel wall plate. As well as providing the load-bearing required to support the mass of the twin pendulums and the driving weight, this also ensures the requisite stiffness of the system. The case is suspended independently of the back plate.

9. One of the movement support pillars on the back plate. The dove-tailed wedges are clamped into sockets on the back of the movements.

Case

BUCHANAN is more than capable of producing every element of any clock commissioned, as is apparent from its earlier clocks. However, in this instance the manufacture of the case was put out to a local maker of musical instruments, Andrew Durand.

Durand, the third generation in THE MUSIC ROOM WORKSHOP, his family business, took the brief: a flame mahogany case (**rear cover**) with minimal frame members and maximum glass area. The sides and front of the case can be lifted off the backboard as a unit, **1**, to provide easy access to the movements. All brass parts, hinges and locks for the case were supplied by BUCHANAN.

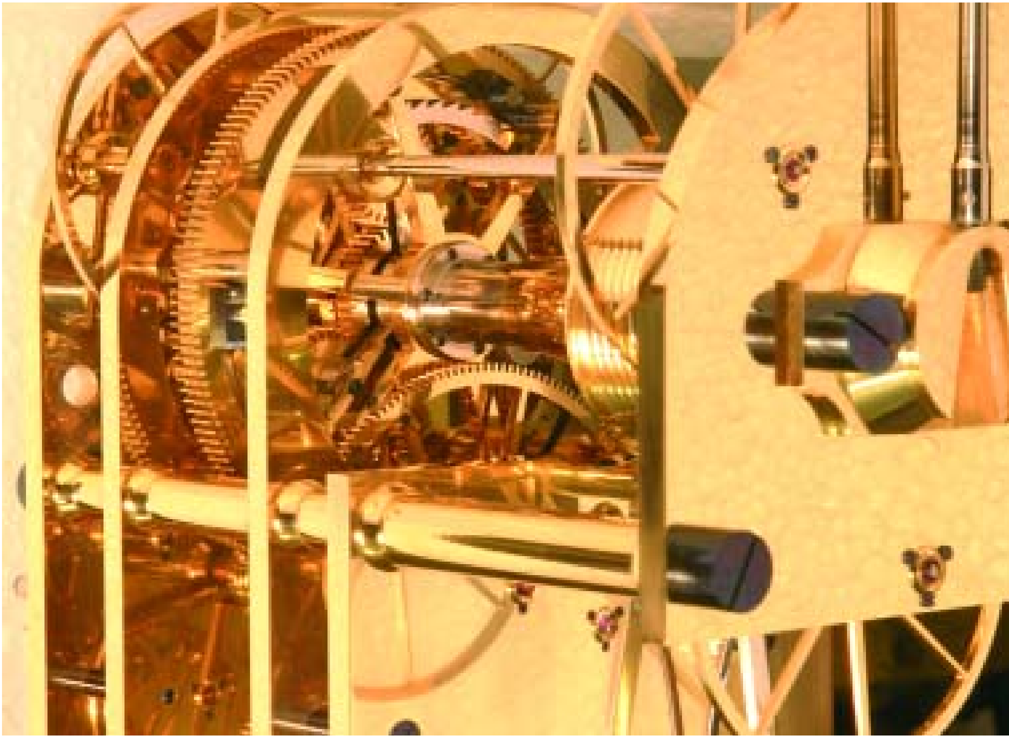
As with the rest of the clock there is considerable attention to detail and the use of traditional methods and materials. These posed a number of challenges, not least of which was the sheer size of the back-plate, and it required something of a search for Durand to find a single sheet of veneer, with a suitable flame, to cover the complete area.

The full-length 'piano' hinge running down the right-hand-side of the door is completely hidden, as are the four catches, all designed and made by BUCHANAN. Each catch has 21 parts and while each locks individually they release as a group.

Known only as 'BUCHANAN No. 4' this has been a considerable undertaking, even for a company which specialises in work of this kind. Not only has it required a considerable knowledge and understanding of the work of earlier clockmakers, it has also demanded a very high level of technical competence and a dedication to highest standards of finishing. While Breguet is renowned for the excellence of his achievements, it seems certain that he would be more than impressed by what BUCHANAN has achieved here.

Parts List

The two movements comprise: jewelled bushes (in chatons), 132; chaton screws (1.2, 0.8 and 0.5 mm), 382; other (plain) jewels, 22; anti-friction wheel assemblies, 264; plates, pillars and plate screws, 90; winding barrel and maintaining assembly, 156; train gears and pin wheels, 108; escape wheel assemblies, 50; yo-yo weight, 5; escapement components, 126; sidereal train, 70; sidereal dial and hands, 30; equation of time mechanism, 134; equation dial and hand, 40; thermometer, 84; pendulums, 126; pendulum support bracket, 80; back plate assembly, 40; door catches, 86; hinges, 14 case trim (brass), 14; case (mahogany and veneer), 26. This adds up to an eye-watering 2234; all (except the thermometer fusee chain) made and finished individually by hand!



11. Rear view of the upper portion of a movement showing the barrel and planetary winding gears. Note the anti-friction wheels supporting the arbor and the jewelled chatons for the pivots. The clamp socket (extreme right) fits on a support pillar. As with all views of this clock, reflections can be confusing (as well as adding information).

Contacts:

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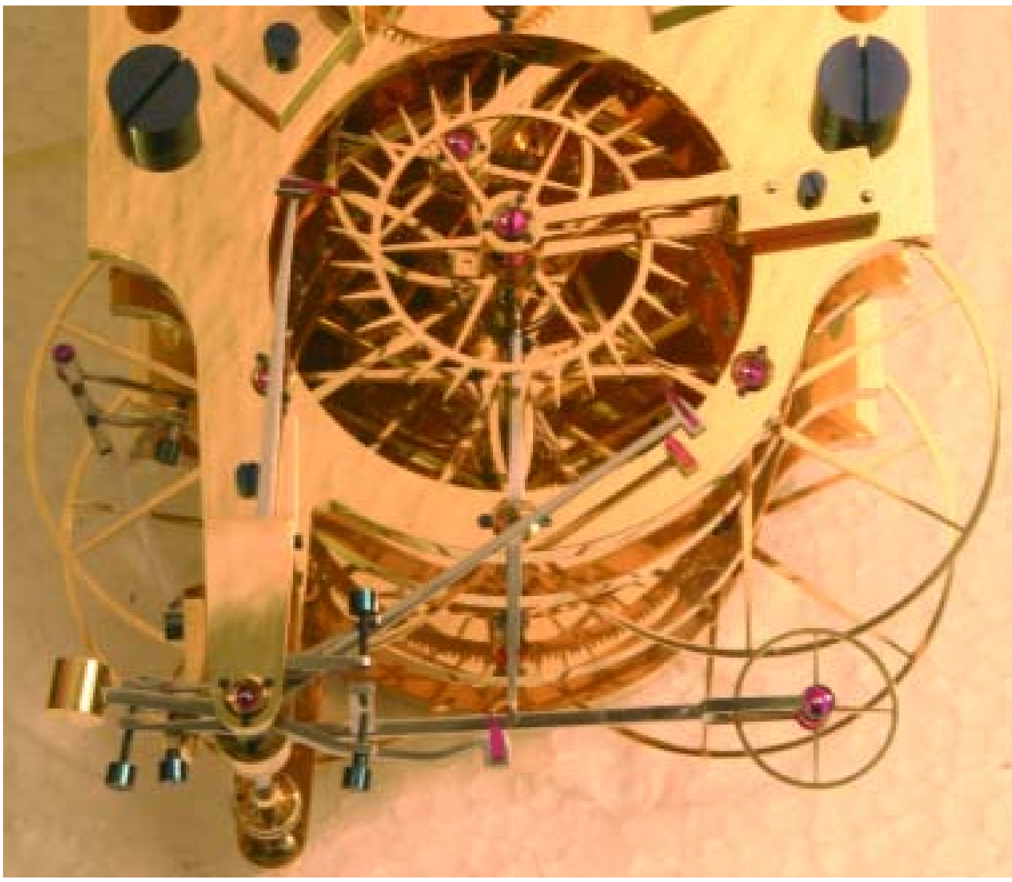

*12. The escapement of the left (solar) movement. Compare with the drawing, **3**.*