Constant Force

Throughout the history of their craft, watchmakers have had a number of 'Holy Grails'. Some of them, like the unbreakable mainspring, dust, shock and water resistance, have long been achieved; even the lubrication-free watch may be achievable with Jaeger-LeCoultre's 'Extreme Lab' concept. But now another chalice may be added to the collection – the Constant Force Escapement.

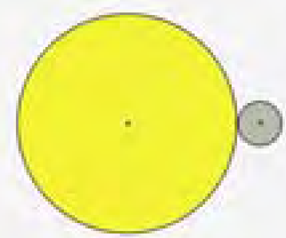
Timothy Treffry

QP readers will be familiar with the fact that timekeeping in a mechanical watch depends on the frequency of the balance. The balance is not, however, a perfect oscillator, its frequency varies if its amplitude changes. This will happen if the impulse delivered by the escapement varies. Unfortunately it does; and the explanation lies with the unsatisfactory nature of the gear train in watches.

To an engineer, a mechanical watch is an unusual machine; it has to produce an output that is much faster than the input. The mainspring barrel makes three or four turns a day while the escape wheel must make 15,000 or so. To achieve this enormous gain with just four steps, using small gears, means that, at the latter steps particularly, the driven gear only has a small number of teeth. As a result the transmission of power cannot be smooth and the inevitable fluctuations produce a variation in the power reaching the escapement.

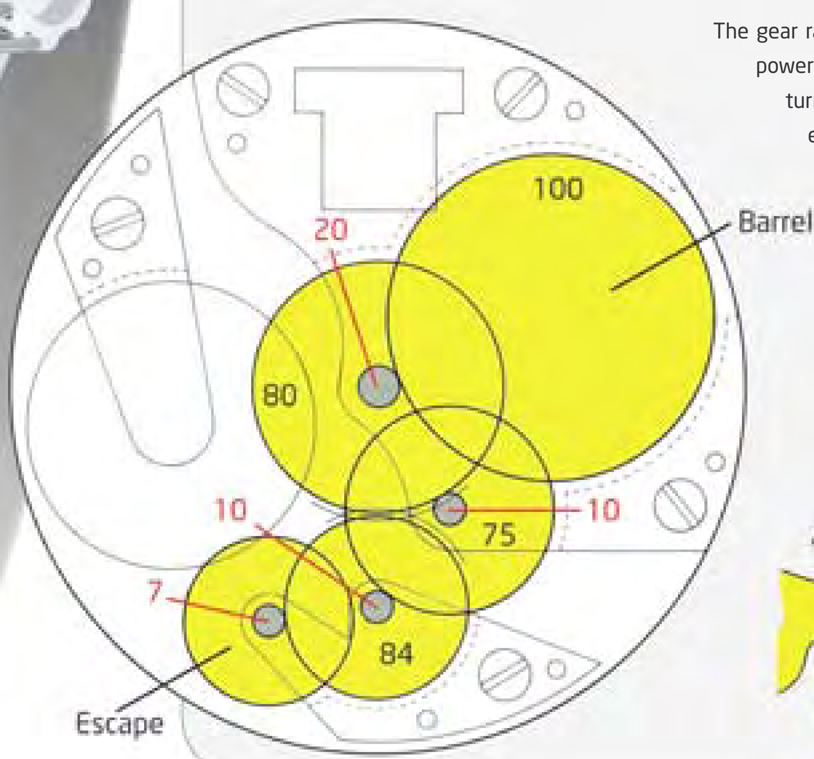
A number of attempts have been made to solve this problem. Patek Philippe's research group investigated the traditional shape of watch gears and, by making the teeth more pointed, was able to halve the variation in the power reaching the balance. This new system was introduced in the Gondolo Calendario (ref. 5135) in 2005.

If the rims of two wheels are touching, when one turns the other will turn. If the larger one is 5 times the diameter of the smaller, when the larger one turns, the smaller one will turn 5 times faster; provided there is no slipping. In a watch it is very important that there is no slipping. We can prevent it by putting teeth on the edges of the wheels turning them into gears. In our 1:5 example there must be 5 times as many teeth on the large gear as on the small one. Horologists refer to the larger gear as a 'wheel' and the smaller as a 'pinion'. The wheel has 'teeth' but the pinion has 'leaves'. The wheels and pinions are mounted on axles called 'arbors'.

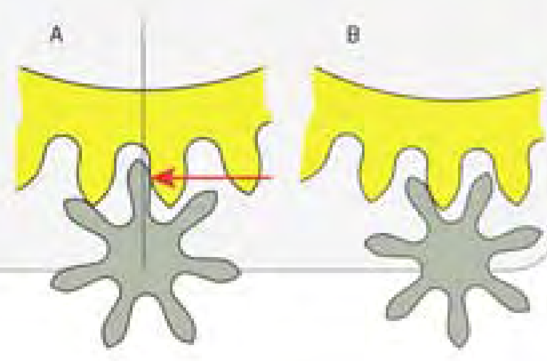


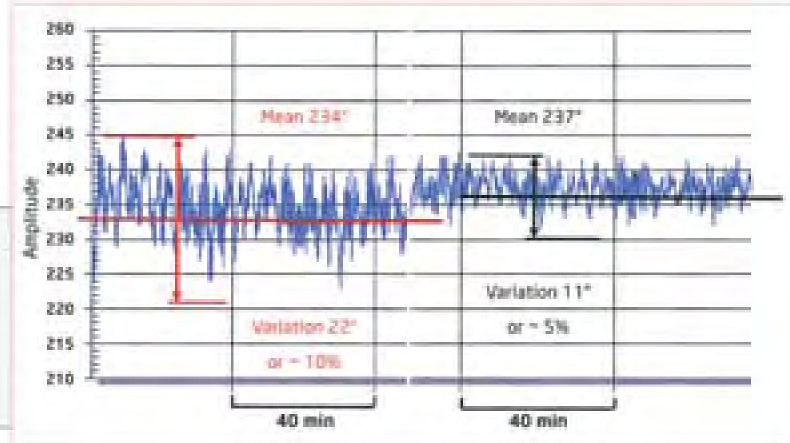
A typical gear train for a 4 hz (28,800 vph) watch: the barrel has 100 teeth and drives a 20-leaf pinion on the 2^{nd} (or 'Centre') wheel which turns once an hour and carries the hour hand. Next the 80 teeth of the 2^{nd} wheel drive the 10 leaves of the 3^{rd} pinion and the 75 teeth of the 3^{rd} wheel drive the 10 leaves of the 4^{th} wheel, which turns once a minute and may carry the seconds hand. The 84 teeth on the 4^{th} wheel, engaging the 7 leaves on the escape pinion cause it to rotate in 5 seconds (12 times a minute). The rotation of the 20-tooth escape wheel, and hence the entire train, is regulated by the frequency of the balance.

The gear ratio between the barrel and 2^{nd} wheel, where the power of the mainspring is greatest, is 1:5 (the 2^{nd} wheel turns 5 times for each turn of the barrel). At the escape wheel, where the power is much reduced, the ratio is 1:12 and the pinion has only 7 leaves.



The transmission of power between wheel and pinion (below) is at its most efficient when the point of contact is close to the 'line of centres' between the wheel and pinion, **A** (arrow). The efficiency drops considerably as rotation occurs and contact becomes more oblique, **B**. This cycle causes the energy reaching the balance to vary, causing variations in balance amplitude.



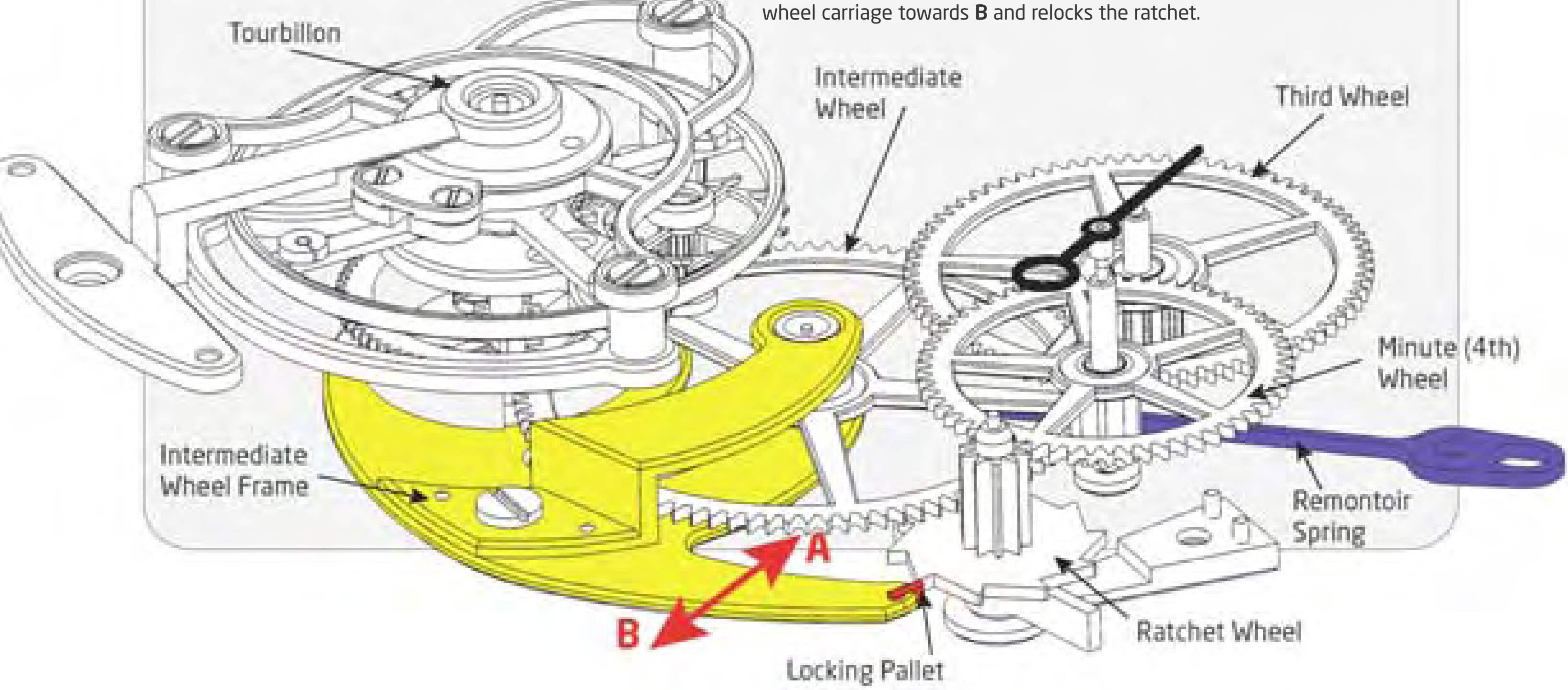


Variations in the energy delivered to the escapement by the standard gear train cause a pattern of variation in the amplitude of the balance. By closely examining these variations watchmakers can identify further imperfections in particular components in the gear train.

By modifying the shape of the wheel teeth in the train Patek Philippe has been able to halve the variations usually found.

The Tourbillon Souverain by F-P Journe has a remontoir to provide a constant force to the escapement. Power reserve is indicated and the minute hand makes one-second jumps. The remontoir mechanism can be seen through a shaped aperture in the watch plate.

In the F-P Journe remontoir the 3rd wheel of the train drives the pinion of the minute wheel and the minute wheel drives a ratchet wheel. The pinion of the minute wheel also engages the intermediate wheel that rotates the tourbillon carriage and drives the escapement. This intermediate wheel is pivoted on a frame that can oscillate as indicated (red arrow). The torque of the minute wheel pinion engaging the intermediate wheel presses it in direction **A**, against the remontoir spring (see view through case back). The locking pallet locks the ratchet wheel and therefore the minute wheel. With the train locked, it is the remontoir spring pushing towards **B** that pushes the teeth of the intermediate wheel across the pinion of the tourbillon carriage to drive the escapement. As the watch runs and the tourbillon rotates, after 6 swings of the balance (one second), movement of the frame carrying the intermediate wheel is sufficient to unlock the ratchet wheel, the minute hand leaps forward one second and the torque now applied to the intermediate wheel again moves the intermediate wheel carriage towards **B** and relocks the ratchet.



In the Academia Tourbillon the gear train applies torque to a 4-armed weight on the 4th wheel. This energy tensions a spiral spring attached to a sleeve on its arbor forming a reservoir of energy for transfer to an intermediate wheel that drives the tourbillon carriage providing a more constant and immediate source of impulse to the balance. Note the unusual shape of the escape wheel; it is made from nickel by electroforming.

To an engineer, a mechanical watch is an unusual machine

The tourbillon greatly exacerbates the problem of delivering constant force to the escapement. In a tourbillon the gear train drives the rotation of the tourbillon carriage and this rotation drives the escape wheel. The energy reaching the escapement is dampened by the inertia of the tourbillon assembly. DeWitt relied on a different approach to achieving a more constant impulse in its Academia Tourbillon produced in the following year.

In the De Witt Academia the power of the train is transferred to the tourbillon via a constant force assembly involving a 4-armed flywheel and a spiral spring. This combination provides a buffer between the power supply and the start/stop action of the escapement. In a 4 Hz watch the escapement locks and unlocks 8 times a second. Each time it unlocks, the escape wheel must move sharply to impulse the balance. The spiral spring provides a nearby burst of energy to achieve this.

A more traditional way of achieving a constant force at the escapement is the remontoir. If the De Witt system is like a dam providing a reliable source of water for a power station, a remontoir is like a toilet cistern that is filled and emptied under the control of valves. In a remontoir, energy is regularly stored and released by a locking and unlocking system. As described in QP 26 ('Power Up'), the Lange 31 has a remontoir in the form of a spiral spring whose energy supply is restored every ten seconds.

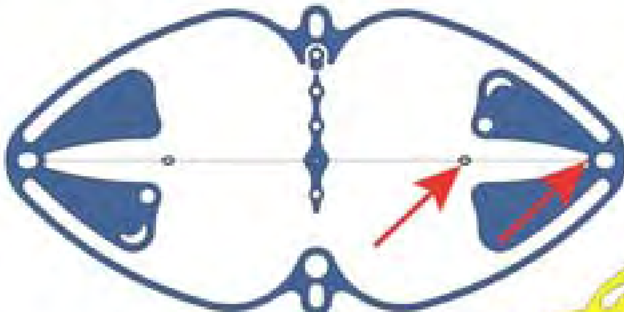
In the Tourbillon Souverain '*à remontoir d'égalité avec seconde morte*' by François-Paul Journe, the remontoir is in the form of a flat spring that is energised once a second to drive the escapement. The action can be viewed through a shaped window in the case back.

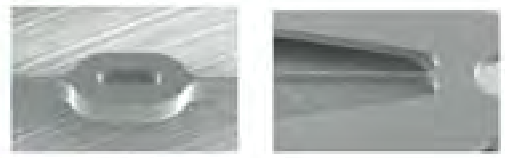
Out of the water

The Constant Force system announced by Girard Perregaux at SIHH 2008 steals a march on anything that has been seen in a wristwatch hitherto. Whereas the systems described previously certainly produce a more even impulse, the power source remains a step or two away from the escapement and its energy is distributed over several swings of the balance. The mechanism produced by Girard Perregaux acts within the escapement and provides separate and identical impulses at each swing.

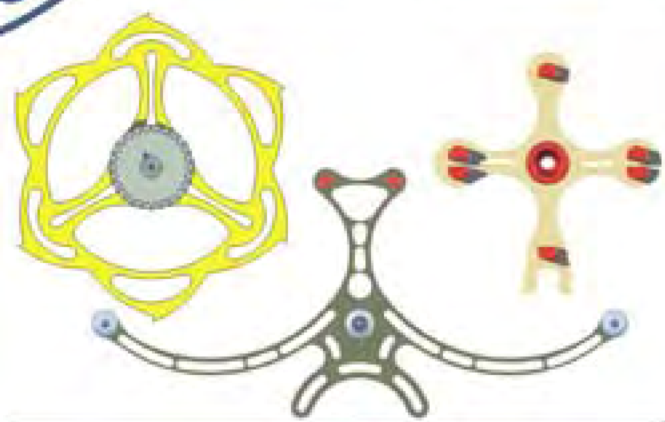
The concept watch shown in Geneva was named 'Constant Girard-Perregaux'. This is a play on words as it both describes the new watch and commemorates one of the key figures in the company's history; children in pious families were often named after virtuous character traits, such as Constant Girard.

GP's idea is believed to have been in a designer's bottom drawer for some time but it was impossible to realise using conventional materials. The new opportunities provided by the production of silicon components permitted a breakthrough. The remontoir spring is within the escapement itself and impulses the lever directly. It is based on the properties of a buckled blade, sometimes known as the oilcan effect. Depending on your childhood experiences, you may have come across it in a 'Put-put' boat or one of



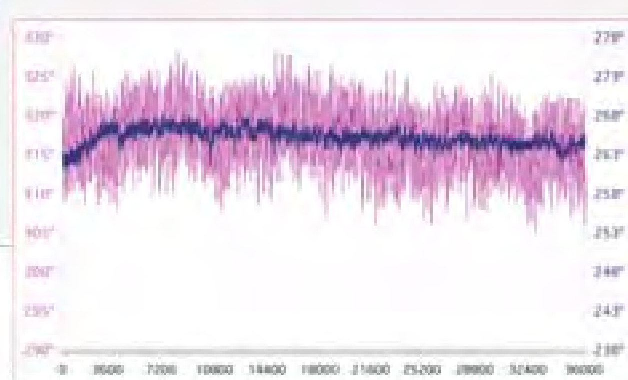


The heart of the G-P system is a complex frame etched in one-piece from a silicon wafer. The electron micrographs show detail of the areas arrowed. The hair-like strip across the centre forms the remontoir spring. The vertical element at the centre is part of the impulse lever. Other components (right) are one of the escape wheels, the winding lever and the remainder of the impulse lever.

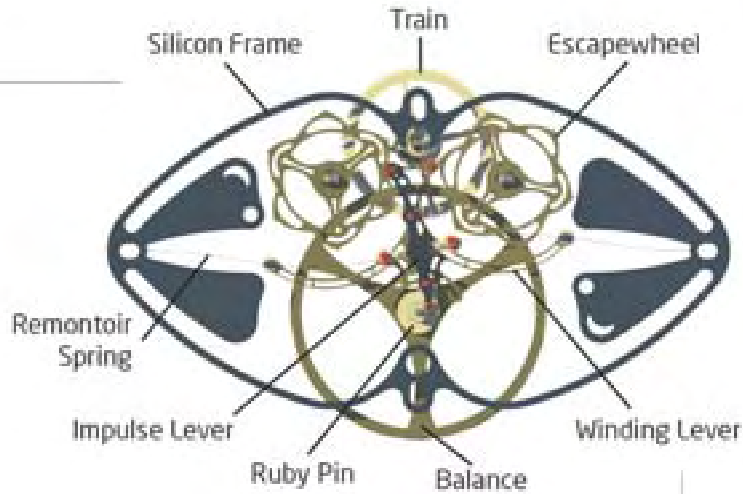


The 'Constant Girard Perregaux' concept watch. The unique mechanism delivers an identical impulse at each swing of the balance.

Energy states in the Girard Perregaux escapement remontoir spring. The red line shows the tilt of the winding arms. **A** and **D** are the low energy states after delivery of impulse. **B** and **C** are high energy 'meta stable' states produced by the gear train and the winding lever. The sequence of states is **A**, **B**, **C**, **D**, and back again.



The red line shows the amplitude of the balance of a watch with a standard Swiss lever escapement, measured second by second over a 24-hour period. The blue line shows the very much smaller variations in the amplitude of the balance of a watch with the Girard Perregaux Constant Force escapement.



When the silicon frame of the G-P constant force escapement is put into the watch it is compressed laterally so that the remontoir spring, being fixed to the impulse lever that is pivoted on the watch plate at the centre of the assembly, is forced into a horizontal S-shape. The train drives the twin escape wheels. These are shaped cams with 6 teeth. The wheels rotate together and they are alternately in contact with a pallet on the top end of the T-shaped winding lever. In the image above, the balance is nearing the end of its clockwise swing. The left hand escape wheel is about to lock on the left pallet (locking both wheels). Pins on the arms of winding lever are located in the lateral holes in the remontoir spring. As the winding lever moves this spring is changed from the relaxed shape **A** (below) to the energised state **B**.

With the escapement locked, the balance swings anti-clockwise until the ruby pin enters the fork on the impulse lever, moving the lever as indicated. This will also move the winding lever, putting more tension into state **B** causing it to flick through state **C** to **D**. Note that the shorter arms of the impulse lever has pallets engaging the remontoir spring. The change from **C** to **D** releases energy to give an anti clockwise impulse to the balance. At the same time the winding lever will move across so that the right hand pallet rests on the rim of the other escape wheel and as it turns the winding lever will energise **D** to produce **C** and, upon unlocking, the **C B** to **A** transition will deliver a clockwise impulse. The energy released by the shape change on unlocking will always be the same so that identical impulses are given to the balance.

The pursuit of constant force is an existential quest

those little metal frogs, which gives a loud click when a spring at the back is pressed.

The remontoir spring, together with its frame and part of the impulse lever, is made in one piece; either etched from silicon or moulded from nickel by electro deposition.[1] The spring (or blade) is considerably thinner than a human hair. Close inspection shows that, with the remarkable precision achieved by these technologies, this spring is widened to form two tiny rings a quarter of the way in from each end. The spring is somewhat longer than the distance across the frame to which its ends are attached. As its centre is fixed to the impulse lever, the spring is forced into a lazy S-shape, for which there are two positions: down-up or up-down. The lateral arms of a T-shaped winding lever, pivoted at the same central point as the impulse lever, engage the aforementioned rings in the spring. As the escape wheels are turned by the gear train, one of them is in contact with the winding lever, tilting it to force the spring close to what Girard-Perregaux describes as a 'meta-stable' state as the wheels lock. When the wheels unlock, the meta-stable form, which has acquired energy from the train, flips into the opposite S shape delivering this energy to the impulse lever to drive the balance. The second escape wheel then acts on the winding lever to reproduce another meta-stable state that will, in turn, impulse the balance in the opposite direction when it is discharged.

The effect of all this, which is a delight to observe, is to provide a constant impulse to the balance. It continues oscillating at a steady amplitude throughout its running period. Eventually there is insufficient power to energise the spring and the watch stops until it is rewound.

There is no doubt that a watch with some type of constant force escapement will give satisfaction to the watchmaker and confer considerable, if expensive, 'bragging rights' to the owner; but is it really necessary? If we look again at those variations in balance amplitude, the mean is the same for the 'ordinary' Swiss lever, the Patek Philippe with improved teeth, and the Constant Girard Perregaux. In the Lange-31, where the power delivered by the mainspring varies enormously over the full month's running time, the remontoir is undoubtedly essential. If the action of the escapement in a tourbillon is sluggish; again a remontoir or a similar device may solve the problem. Precision timekeeping was long ago achieved by other means. But that is not the point. As with many aspects of the mechanical watch, perhaps even its continued existence, the pursuit of constant force is an existential quest. But that will not deter the deep-pocketed enthusiast who is determined to have an example of the latest 'chalice' in his collection.

[1] Silicon has become the preferred approach.

Further information: www.girard-perregaux.com