Upward Spiral

The humble balance spring is undergoing a diamond-studded transformation

Theodore Diehl

The balance spring has been the object of intense scrutiny for hundreds of years. Not for its beguiling appearance, mind you, but because of its key role in accurate timekeeping. *QP* examines the stringent demands placed on the workhorse of the watch, and how Ulysse Nardin are gearing up for a sparkling revolution that defies common belief.

Although their ordinary appearance belies the extraordinary technology necessary to create them, *QP* is pleased to provide the first public photographs of diamond balance wheel spirals (left) and some of the special Dual Direct escapement wheels (right) also cut from diamond, that are utilised in the Ulysse Nardin 'FREAK'. Note the size of the watchmaker's tweezers in comparison to these parts.

Historical arguments abound over who exactly was responsible for the seminal application of the balance spring to a clock's movement (among others, Robert Hooke and Christiaan Huygens both applied themselves to the task in the 17th century). What we *do* know is that the combination of spring and balance quickly became the norm. Pocket watches, then wrist-watches – with greater portability and even higher exposure to timing variations from constant movement and temperature change – raised the demands placed upon this hair thin, miniscule spring to the limit.

It is no wonder that metallurgists, inventors and horologists alike have all applied their talents to this little spiral-formed piece of metal. Today, there is the added incentive of the reward to be reaped by taking on Nivarox's near-monopoly position.

Tricky business

During the past 100 years or so, the primary developments in the balance spring were centered upon the exact form and content of the alloys used in its production. Even today, the exact content of the metals used in balance spring production are clouded with an almost alchemical mystery, not to mention the tricky and precise steps of drawing, rolling, cutting and tempering the metal into a precise shape, with exactly reproducible qualities. Where lies the problem exactly?

As you may know, the balance wheel describes an arc, back and forth, thousands of times an hour. It makes up part of the regulating system of the watch and exactly controls the release of power from the watch mainspring, and thus the watch's accuracy. As the balance wheel turns one way, the spring, to which it is connected, tightens and becomes smaller. As the forces in the spring increase, the rotation of the balance wheel slows until it is momentarily stopped, and then recoils through its natural point of relaxation, before the same braking action recurs, this time as a result of building tension through the outwards expansion. These forces are at play every second as the watch ticks away *ad infinitum*.

One of the very first problems addressed by both Hooke and Huygens was concerned with how the balance spring's regularity varies with temperature change. The trick lies in finding a particular material or alloy that reacts least to temperature variation over normal ranges.

The diamond Dual Direct escapement wheels (left) and the diamond balance wheel spirals (right) all have a deceptively metallic look to them at first glance; only a closer examination provides a hint to their real composition.

How was a spring manufactured from hollow, highly flexible glass tubes, less than 1.5 mm thick at the turn of the 20th century?

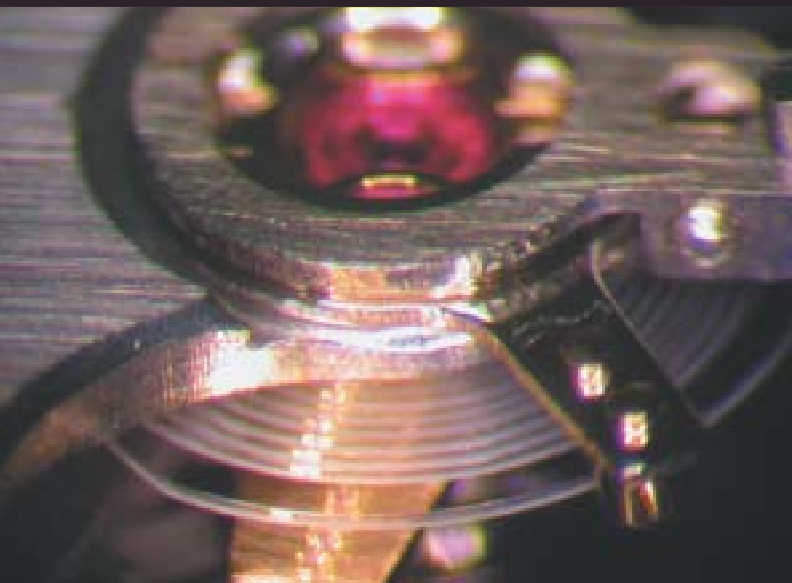
Even with the highly developed alloys used in today's watches, warmth will make the spring slightly longer, as well as 'lazy' in response. The cold will shorten and stiffen the spring, making it 'quicker'. Since it is directly attached to the balance wheel, you can imagine the effect on the time it takes the balance wheel to oscillate, especially at the moment of recoil. Since it is doing so thousands of times an hour, any small discrepancies quickly add up. So ideally, a spring would never be affected by temperature. Add to that freedom from magnetisation, no sensitivity to corrosion from chemicals or air reactants, and limitless flexibility for a lifetime of trouble-free action, and you have the ultimate balance spring. Indeed, you might just have as much luck looking for the Philosopher's Stone.

Inspiration

In actual fact, stone is exactly where one of the newest and most exciting developments has 'sprung' from; namely a balance spring made of pure diamond. Yes, you read correctly: diamond. Ulysse Nardin have been back at work, creating the impossible once again.

Many of you will remember UN's Freak, which utilised specially developed techniques for the creation of its custom-made silicon gears, used in the Dual Direct escapement system. Never before had such hard material been applied so successfully to watches. These techniques were borrowed from developments in the micro-mechanical industry and the world of electronics, chips and circuits, whose domains grow more intertwined by the year. The Swiss company, CSEM was instrumental in working with UN to create the Freak's silicon gears. The construction technique uses a gas-filled chamber in combination with highly charged magnetic fields. The gases erode unmasked areas of the material, virtually molecule by molecule

UN's jolt of realisation that such an adventurous project was worth investigation came during an afternoon's clear-out of old parts stored away in a closet. In times past, UN were well known for their marine chronometers and were leaders in



(Above) Functioning diamond balance spring, mounted in the escapement. One arm of the balance wheel below is just visible near 6 o'clock. Although diamond is unbelievably tough and flexible, insertion and regulation of the spring requires special techniques to avoid breakage. The balance spring stud, which holds the outer end of the balance spring is visible at 3 o'clock.

(Right) View of assembled diamond Dual Direct escapement wheels. Note the interstitial spaces created by the removal of excess material from each tooth in an effort to lower inertia. Diamond is ideally suited for this, as the DD escapement requires the lightest possible wheels coupled with extreme hardness and durability.

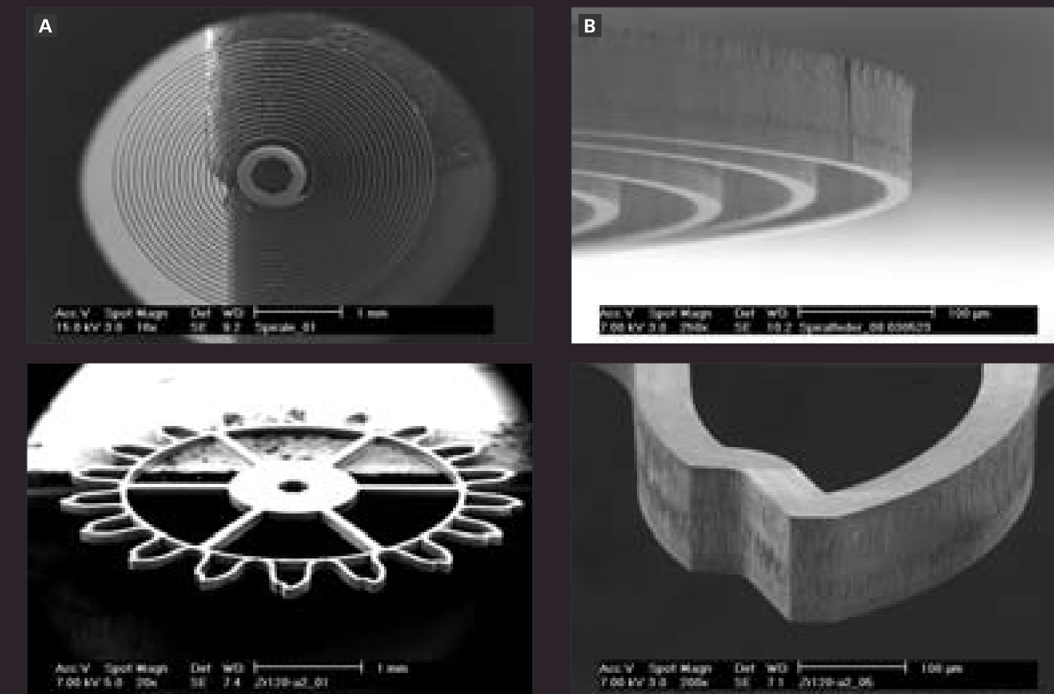
this field. One of the boxes they found contained several cylindrically shaped springs made of hollow glass tubing, for use in just such marine chronometers. No documentation of any kind could be found in the UN archives regarding such glass spring experiments, nor the clocks produced as a result. The oldest living employees were asked if they had ever heard rumours of such experiments being done. No one had a clue. In fact, no one can figure out how such a spring could have been manufactured at the turn of the 20th century from perfectly round and *hollow*, highly flexible glass tubes, less than 1.5 mm thick. This private mystery from UN's past served as an inspirational motive to examine the impossible.

We think of diamond as being a hard and inflexible material. After all, we are always being told that it is the hardest material on the earth, and we have adopted this mindset unquestioningly. But when diamond is cut to such thin and delicate dimensions, hidden properties become apparent. The mechanical elastic properties of diamond (as expressed by Young's modulus) are in the region of 1,143, whilst that of steel is between 190 and 250. Simply stated, this means that diamond can withstand about four and a half times more 'elastic stress' (such as bending, twisting, stretching) than steel, before permanent deformation occurs. Not exactly the way we think about diamonds, is it? Even harder for our imagination to grasp is the fact that despite this flexibility, diamond retains a hardness and fracture strength far above any other material available.

Technicalities

Both Hooke and Huygens voiced concerns about the problems regarding thermal sensitivity of balance springs centuries ago. Well, both gentlemen would approve of the thermal properties of diamond, as artificial diamond has the highest thermal conductivity at room temperature of any material known to man. Such extreme conductivity means that heat and cold 'pass through' diamond easily and therefore have little or no residual effect upon it. Whereas a normal metallic balance spring might take several hours to cool down to normal temperature after the watch has been in the sun, (with all the inherent timing variation this causes) a diamond spring will barely hold this heat at all.

The creation of these diamond balance springs with this process (as well as other fine parts, such as gears) goes a step further than UN's previous work with silicon. In the first place, a layer of artificial diamond must be created on a silicon wafer via chemical deposition, using a plasma environment. The etching process is also more critical with diamond, as its atoms are tightly bonded to one another and don't part company as easily. This is a critical issue, as the *modus operandi* behind plasma ion technology is the repulsion of atoms from the material being



(A) Electron microscope view of test spiral. Bar line scale represents 1 mm (0.0394 inch)

(B) Notice the flat profile in this electron microscope view of a diamond balance wheel spring. The bar line represents the scale for 100 micrometers (3.94 thousandths of an inch).

(C) EM photograph of the new 'Dual Indirect' escapement wheel in which UN's recent improvement to the tooth profile is clearly visible. (The little notch at the end of each pointed tooth). This new application of diamond was a good reason to further refine and develop the original DD escapement to the second generation.

(D) The 'Dual Indirect' escapement's 'extra notch' in super close up. The bar line represents the scale for 100 micrometers (39.4 thousandths of an inch).

When diamond is cut to such thin and delicate dimensions, hidden properties become apparent.

cut. The creation of silicon parts, in this sense, was an easier task, as its atoms give way more readily, and artificial silicon wafers are part and parcel of the chip-making industry.

Watch this space

You might then ask why UN did not create springs from silicon in the first place, given their aforementioned experience with gears? The reason for this is that silicon has a Young's modulus even lower than steel, and has a much lower thermal conductivity, only somewhat better than standard metal alloy spring material. A piquant detail here is that a consortium comprised of Nivarox, Patek Philippe and Rolex (together with CSEM – UN's old partner in the silicon gear project) recently announced the successful creation of silicon balance springs. The results were interesting, but the group admitted publicly that silicon was too temperature sensitive to be useful for spring production, and they are continuing their research. UN continues to lead developments in their own unique way.

So, will we be seeing new UN wristwatches with diamond balance springs soon? The answer, for now, is no. Although the diamond balance spiral has proved its usefulness, it also requires new techniques of construction and assembly in the watch itself, and no watchmaker in the world has any experience in dealing with it. Before it can be utilised on a broad platform, the horological world will have to become accustomed to working with such new technology, and that will take years. For now, UN will be keeping this jewel of an idea in their pockets, with the happy knowledge that they have accomplished the impossible, yet again. ○

Further information: Tomillo Ltd, 3000 Cathedral Hill, Guildford, Surrey GU1 7UB.
Tel: 01483 243 588, Fax: 01483 243 501, E-mail: tomillo@xs4all.nl, www.ulysse-nardin.com