NEW TECHNOLOGY

CARBONTIME™ a New Oscillator for Mechanical Watches

Gideon Levingston describes a new watch to be shown at Baselworld 2006. The balance assembly, which he invented, is insensitive to temperature and magnetic fields

The balance spring in a watch vibrates the balance wheel with a period of oscillation that should be perfectly regular (isochronous) in all conditions. Traditionally, both the balance wheel and spring are made of metal and therefore are adversely affected by changes in temperature and, if containing iron, the presence of magnetic fields.

In metals, which are crystalline solids, the elastic (Young's) modulus, E, increases with the bond strength between atoms. As temperature increases, the distance between the atoms increases and the bond strength weakens and elasticity decreases. This change in elasticity with temperature is known as the thermo elastic coefficient and was classically the major problem with balance springs.

Temperature is only one of the external influences concerning the spring in the watch oscillator. The other is change of E due to magnetism. This was discussed in an earlier article[1].

A metal balance wheel expands as temperature increases (its radius, r, increases). Traditional balance springs, made of a ferro-nickel alloy, also expand with an increase in temperature. When the balance wheel expands its inertia increases and maintaining its oscillation becomes harder. So the spring needs to have greater elasticity to keep the system isochronous. The inertia of the balance wheel, I, is equal to the gyratory mass, M, times the square of the radius, r:

$$I = Mr^2$$

Thus a small change in radius causes a larger change in inertia.

The balance must compensate for this by either having a spring with an abnormal change of E with temperature, as with the alloys currently in use, or by having the gyratory mass decrease with a rise in temperature. A more satisfying solution is to use materials where neither E nor r vary with temperature.

Historically, the most successful attempts to reconcile this problem have been by Charles Edouard Guillaume in 1899, with his bi-metallic compensating balance wheel and steel balance spring, and the coupling of Guillaume's 1912 ferro-nickel spring, with a steel and invar ovalising balance, by Hamilton in 1943.

Despite their useful thermal characteristics (they get more elastic with a rise in temperature in the ambient range) ferro-nickel alloys are sensitive to magnetism. This disturbs the elastic modulus of the spring and causes negative effects to the precision (isochronism) of the timekeeper. If optimal behaviour of the oscillator is required, the spring material must be changed. This is what I set out to do.

The term 'auto compensating' balance spring, used by the industry, only applies when the spring is used with the balance for which it was designed. The metal normally used for the balance wheel is Glucydur. It is a Cu/Be (copper beryllium) alloy and has a linear thermal expansion coefficient of 17×10^{-6}/K (A copper-gold alloy with a similar expansion coefficient is also used). This is a deliberate and calculated partnership, matching the elasticity of the Fe/Ni spring with the expansion coefficient of the balance alloy. However, if a balance wheel with different properties were coupled to a standard balance spring this would not produce an isochronous result.

Relationship between Balance *r* and spring *E*

The intrinsic requirements and characteristics of both the balance and the spring must be considered to achieve a solution to the problem.

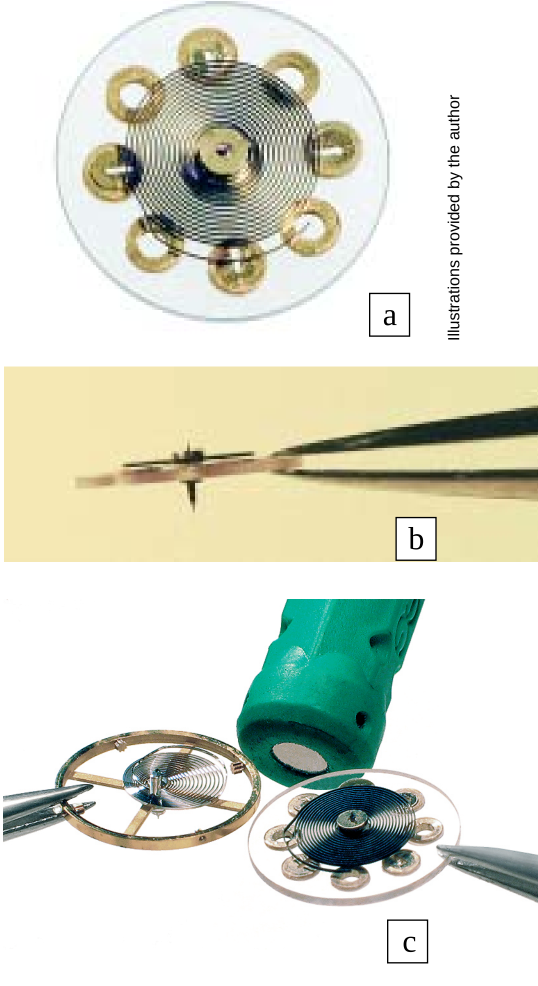
The variables r and E which are affected by temperature must be brought into a constant relationship represented by the following expression:

$$r^2/E \quad \text{or} \quad r/\sqrt{E}$$

where r is the radius of gyration of the balance and E the elastic Modulus of the spring.

Graph, **1**, shows how the E of the spring and the r of the balance vary with temperature. It also shows the inflection in the gradient of the elastic modulus at

Watchmaker Kari Voutilainen has a world first with this white gold chronograph incorporating the new Carbontime™ quartz balance and 'carbon' spring. The case was made by Gideon Levingston.



Illustrations provided by the author

*Metal discs let into the periphery of the quartz disc, **a**, provide the necessary gyratory mass for the free-sprung balance. The U-shaped inserts are used to adjust timing. The side view, **b**, shows the profile of the assembly. A magnet, **c**, demonstrates an important difference between the conventional and the Carbontime balance.*

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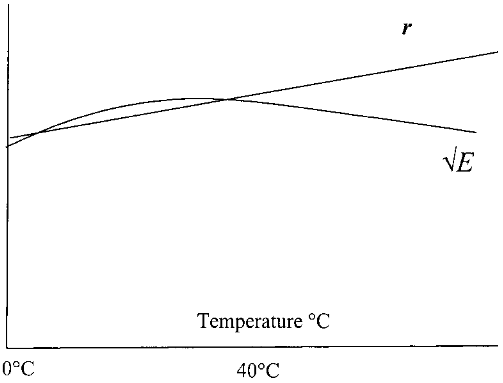
[1] 'A New Material for Balance Springs', *HJ*, **146** [7], p243, July 2004, see www.carbontime.com)



1. The relationship of balance wheel radius, r, and spring elasticity, $\sqrt{E}$, with temperature change. Spring alloys whose anomalous behaviour provides a fairly stable relationship at ambient temperatures are chosen. The vertical scales have been adjusted to emphasise the relationship between $\sqrt{E}$ and r.

around 40°C. Spring alloys have been chosen to match the behaviour of the balance wheel over the ambient temperature range. When springs containing iron are exposed to magnetic fields, the inflection point of the $\sqrt{E}$ curve shifts permanently to a lower temperature and watch performance on the wrist is affected.

In order to better the existing arrangement, I studied materials which are magnetically inert and thermally very stable in the ambient range (and over a considerably greater range), which also show the desirable qualities of low modulus damping, low creep, low permeability and low density, as well as having low linear expansion coefficients in the desired directions and the required tensile strength.

The method I adopted was to make a spring material for which the variation of E with temperature is small (and can be +ve or –ve), and then devise a very low thermal expansion balance which is 'tuned' to the particular balance spring, **2**.

The relationship between thermal coefficient of the balance wheel a_1, and of the balance spring a_2, is given by:

$$U = a_1 - 3a_2/2 - \delta E/2E.$$

With an appropriate choice of materials, U can approach zero.

2. At 2 and 8 o'clock, in this 'ultrafine compensation' balance, tantalum discs are attached to curved strips which will move them inward when temperature rises, providing inertia reduction when required.

Proposed Solutions

Once the correct relationship between balance spring and balance wheel is found, the number of permutations is not limited to particular materials.

To provide a solution to the relationship $r/\sqrt{E}$, first a spring with a near linear thermo elastic change is required. I have selected a material of linear and low thermo elastic modulus, <1% between 0 and 80°C. In my earlier work[1] I used continuous carbon fibre. Following further development, the materials now being used include variously treated crystalline and non-crystalline carbon. To match this I needed a balance wheel with a low expansion coefficient and, if necessary, ultrafine compensation, **2**.

In order to achieve an absolute minimum, I chose fused quartz (96-99% silicon dioxide), an isotropic ceramic material. This has a thermal expansion coefficient of between 1.0 to 1.5×10^{-6}/K and ensures a limited change of r with temperature. Once a balance spring has been chosen, a suitable quartz balance can be selected to give a very low value for U in the equation above.

A further problem remains. Quartz has low density and requires loading to satisfy the amplitude and frequency requirements of a watch balance. From a variety of magnetically insensitive metals I chose gold and tantalum rings which dilate about a true centre with temperature change and allow for poising and timing, as the whole system is free sprung. The weights are set in recesses in the quartz disc to reduce air friction.

True accuracy comes about when r and E do not vary with temperature. This has virtually been achieved. The principles of the solutions devised are contained in my second international patent application.

A British company, CARBONTIME LTD, is developing production of these oscillators and the technology (which will be made available to the industry), and is presently being employed in the development of a world first limited series of watches containing the CARBONTIME™ balance spring and balance wheel.

For further information, including previous articles, see: Carbontime.com ❐

NEWS

Watchmaking Alliance

A NEW watchmaking alliance, ***Time æon***, has been formed between (L to R above) Stephen Forsey, Philippe Dufour, Vianney Halter, Kari Voutilainen and Robert Greuble. They refer to themselves as '*Watchmaker Compagnæons'* highlighting the diphthong to indicate the association of skill, mind and principle in their work on Time. They feel that while individual watchmakers have created many of top of the range complicated watches promoted by luxury brands, their achievement has been obscured. TIME ÆON will be used to promote the contribution, ideals and creativity of individual craftsmen as well as providing a grouping for the interchange of ideas.

Company illustration