New Developments in Timepiece Regulators – SSC Study Day 2014

The Société Suisse de Chronométrie (SSC), hosted a study day in September dedicated to the “Vectors of Innovation in Watchmaking – Materials, Design and Calculation”. The conference was held at the new SwissTech Convention Center on the campus of the Swiss Federal Institute of Technology in Lausanne (EPFL).

There were many presentations including subjects such as developments in colored ceramic materials, the characterization of the elastic properties and deformation of the nickel-phosphor materials used in the LIGA process, measurements of acoustic elements (read: repetition going) using a Doppler laser, etc.

For me, the two most interesting presentations had to do with new implementations of the regulating organ of mechanical watches, the Genequand regulator and the IsoSpring regulator. The Genequand regulator is an implementation of John Harrison’s grasshopper escapement for clocks (1730) using flexible elements instead of pivots. This escapement is combined with a new pivotless oscillator with very high quality factor, greatly increasing the autonomy. It is also entirely implemented in silicon.

The following report presents my own explanation of the presentation of the IsoSpring regulator by Professor Simon Henein [1]. This regulator is based on a different concept than the oscillator systems used as the time base for today's watches and pendulum clocks. This regulator has been dubbed "IsoSpring", but I would prefer to call it "Orbital", as it is based on the physics of celestial movement, the orbits of the planets as described by Kepler and proven by Newton. These concepts lead to an orbital regulator that does not require an escapement. It does not chop the time into short periods, ticks, but produces a continuous controlled movement.

Professor Henein started the presentation with a quick, but in depth, history of modern escapements, mechanisms that is used in all mechanical clocks and watches made today. We remember that one of the main requirements for a precise, practically usable time base is that its oscillating frequency be independent of the amplitude of oscillation. This property, known as isochronism, makes the timekeeping independent of the fluctuations of the energy source. The isochronism principle was discovered by Galileo and implemented first by Christiaan Huygens, in 1656 for clocks with the pendulum and in 1675 with the balance hairspring (in parallel with Hooke) for watches. With these improvements the accuracy of clocks went from an error of 15 minutes a day to about 15 seconds a day, a tremendous improvement of almost two orders of magnitude.

Subsequent advances were less spectacular, the chronometer escapement bettering the timekeeping, the Swiss anchor escapement and certainly the introduction of draw on the anchor bettering the reliability. From that time (1800) to now the advances have been small and incremental, many tiny improvements that all together have lead to the level of timekeeping and reliability that we see today. But these regulators are all based on simple oscillation, the movement of a mass with a restoring force, be it gravity in the case of a pendulum or a spring in the case of a balance wheel. That balance wheel must continually stop and change direction.

The novelty of the IsoSpring orbital regulator is that it is based on the orbits of the planets around the sun, yielding unstopped rotation. The basic concept goes back to 1687 when Isaac Newton published the Principia Mathematica. His most famous result was to show that the celestial movements could be explained by a few simple principals and to prove the laws of Kepler governing the elliptical orbits of the planets around the sun, the sun being at one of the focii points of the ellipse.
In the same paper Newton showed that replacing force of gravity from the sun by a central linear force of attraction, the orbits remain elliptical and that the period of rotation of the planet is always the same. It is this isochronism property of orbits that is used by the IsoSpring orbital regulator to create a constant rotational speed regulator, i.e., the size of the orbit can vary, but the period of rotation remains constant.

This can be imagined as a kind of sling with elastic bands. If you put a stone in a sling and let it rotate with differing applied force, the elastics will stretch differently giving different diameters of the stones trajectory, but the period of rotation will remain the same. Newton proved that this type of system is isochronous, i.e. that the period of rotation is only dependent on the mass and the rigidity of the spring holding it.

Of course, the mathematical proof depends on several assumptions, each of which could pose a problem for a physical realisation. In particular, the assumption of a point mass with zero moment of inertia is physically impossible. This needs to be taken into account.

The diagram shows a schematic realisation of such a system. The presentation continues with a long treatment of the error caused by the inertia of the rotating mass on the system. It is shown that this can be so much that the system could be useless as a timekeeper, but improvements are possible.

Moving on to the physical realisation two different models are described. The figure below shows a realisation using flexible blades for a slingshot type embodiment. But even when optimised this type of realisation will have errors caused by the rotational inertia.
A method to eliminate the rotational inertia is to reduce the number of rotating pieces in the realisation and to use a mass that does not turn. A mass that does not turn is equivalent to a planet that travels around its orbit without changing its orientation, in which the day and the year have the same length. Such structures can be made using flexible guidance systems known as compliant mechanisms. Compliant mechanisms have become quite popular in the last 15 years or so. This system allows the mass to move with 2 degrees of freedom, x (left-right) and y (forward-back), but not to rotate. The springs realise a system in which the restoring force always points toward the center. This type of system is called a central spring.

The figure below shows an implementation of a central spring. We can see the two thin horizontal blades at the top and bottom that allow the movement in the y direction as well as providing the restoring force in this direction. Inside that structure we see the vertical blades providing the flexibility in the x direction as well as that restoring force. It is easy to see that the mass in the middle can move in x and y directions and which allows a rotational trajectory while movement in the third direction, z, is not possible.

To power such a regulator, the planet mass must be driven continuously with a circular motion. To this end, a crank is used. The crank must have a variable length as when more force is used to turn the crank, the orbit of the mass will be larger, but as we know the period of rotation will remain the same, except for any residual isochronism error. As the only part that is turning is the crank it is simple to keep its moment of inertia much less than that of the planet and have a theoretically excellent isochronism.
This type of regulator results in a major simplification of the regulating system of a timekeeper. As there is no escapement the losses of the escapement (over 50%) are eliminated and use of compliant mechanisms instead of pivots results in a high quality factor (Q). It is hoped that very good results in terms of power reserve and timekeeping will be obtained in the future using this system. Of course there is still much to learn about the implementation of this kind of regulator, its reliability and timekeeping performance in the "real world". This is the subject of ongoing research and development at the INSTANT-LAB of the EPFL in Neuchâtel.

I would like to thank Prof. Henein and Mr. Vardi of the INSTANT-LAB and the SSC (http://www.ssc.ch) for their friendly support with this report and allowing me to use some images from the papers of the Journée d'Etude - Les vecteurs de l'innovation en horlogerie 17.09.2014.

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