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Research paper

On the dynamics of a high frequency oscillator for mechanical watches

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ABSTRACT

This paper presents a new mechanical regulator for wrist watches, highlighting the methodology used to set up a comprehensive model of the device.

The mechanical regulator, which is characterized by a high frequency monolithic oscillator made of monocrystalline silicon coupled to a deadbeat escapement, has been designed to provide a high quality factor, a condition necessary to guarantee enhanced chronometric performances compared to traditional mechanical regulators. The chronometric performances and the isochronism of the oscillating system have been assessed by means of a multi-body model whose parameters have been evaluated by FE and CFD simulations.

1. Introduction

In the field of mechanical watchmaking the continuous improvement of the chronometric performances has led to the development of many different technical solutions over the years. *Tourbillons, carousels, remontoire d'égalité* and many other types of regulators are among the technical solutions developed in centuries of watchmaking to address the various root causes that affect the isochronism of the oscillator as a necessary condition to achieve better and more uniform time discretization, i.e. isochronism, in different working conditions (the interested reader can make reference to [1] for a broader theoretical background about the mechanics of wrist watches).

In fact, the mechanical regulator is responsible to guarantee the accurate and precise time discretization, allowing continuous and smooth motion of the gear train that connects the main barrel (the source of mechanical energy) to the mechanical regulator. The mechanical regulator is commonly made up of an escapement system and an oscillating system that interact one with each other by means of an anchor, ensuring the periodical engagement and disengagement of the escapement wheel at a frequency that should be as constant as possible, i.e. isochronous.

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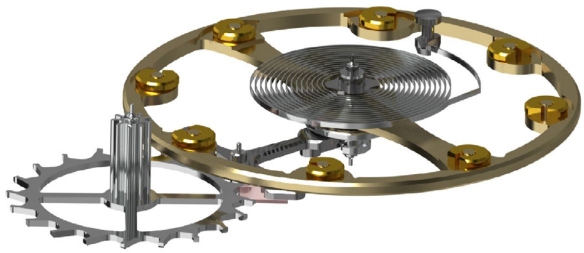
(a) New mechanical regulator



(b) Traditional mechanical regulator

Fig. 1. Mechanical regulators for wrist watches.

Generally speaking, the main mechanical issues that lead to poor chronometric performances of the mechanical regulator can be divided into three broad classes:

- chronometric errors due to the position of the watch in space, i.e. associated to variations of the equivalent stiffness of the oscillator due to the relative orientation of the gravity field;
- chronometric errors due to the variation of the driving torque generated by the main barrell, that results in a variation of the oscillator's amplitude and thus of the relevance of non-linear effects;
- chronometric errors due to the disturbances of the free oscillation phase of the oscillating system generated by the escapement system.

Experimental and theoretical studies during the past years have shed some light over the main causes affecting the isochronism of the oscillator. The quality factor Q, a unitless number whose physical meaning is associated to the energy lost per cycle by the oscillator owing to the dissipative effects, has been proven to affect the chronometric performances of every kind of watch quite significantly. Vardi in [2] has investigated the effect of the quality factor on the dynamic behaviour of mechanical regulators, showing that, in general, the higher the quality factor the lower the disturbances generated by the escapement system on the oscillator's isochronism, hence providing better chronometric precision over a given time interval (see also [4,5]). The reasons behind this physical behaviour are not yet fully understood (see [2,3]). However, it has been suggested that the main causes are connected to the transfer of energy from the escapement system to the oscillator, affecting its free motion.

The aim of this work is the study of an innovative mechanical regulator for wrist watches, characterized by an oscillator with a high quality factor and by an escapement system that reduces as much as possible the negative influence of the escapement device on the isochronism of the oscillator. The implementation of such solution relies on the use of a monolithic oscillator with a compliant hinge coupled to a deadbeat escapement (Fig. 1a), a completely different mechanical regulator compared to the traditional swiss anchor escapement interacting with an oscillator characterized by a flywheel, hairspring and balance shaft (Fig. 1b).

After a first part dedicated to the necessary theoretical background concerning isochronism and quality factor, the second part of the work is related to the elasto-kinematic and dynamic optimization of the oscillator, which is made of monocrystalline silicon, by means of a non-linear Finite Element (FE) technique. The optimization allows to determine the best configuration of the compliant system, both in terms of dynamic response and structural integrity. The quality factor related to the structural characteristics of the device has thus been computed starting from FE simulations of the complete system. On the other hand, the quality factor related to fluid dynamics contributions has been computed with a Computational Fluid Dynamics (CFD) approach, obtaining the characteristic damping properties related to the fluid-oscillator interaction.

The third part of the work is related to the modelling of the mechanical regulator by means of a multi-body approach, starting from the stiffness and damping properties of the system previously assessed through FE and CFD techniques. The aim is to study the dynamics of the mechanical regulator in different working conditions and to assess its isochronism with a faster methodology compared to the one based on the use of a FE discretization of the complete mechanical regulator.

The acronyms listed in Table 1 are used in this paper.

2. Isochronism and quality factor

2.1. Isochronism

With the term isochronous we mean the intrinsic property of an ideal oscillator to keep its period of oscillation, and so its oscillating frequency, constant regardless of its oscillation amplitude and external perturbations. This is a necessary condition to guarantee high chronometric performances measured in terms of seconds lost/gained per day.