Design of a stabilised environment for an ultra-stable optical resonator

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A highly accurate and stable optical frequency standard, also known as the optical clock, is widely adopted in many laboratories worldwide. It is a key component for a wide area of research including high-accuracy spectroscopy on trapped particles or a high-sensitive interferometry for gravitational wave detection. The heart of any optical clock is an ultra-stable highly coherent laser that serves as the interrogation laser (clock laser) for long-lived atom transitions and largely determines the clock's stability. However, the coherence time of today's most stable lasers, typically on the order of a few seconds, remains notably shorter than the coherence time of optical clock transitions in neutral atoms or ions. As a result of these limitations, considerable emphasis is directed toward developing clock lasers with low-frequency noise[1].

The general approach thus far involves stabilising the laser frequency to a passive high-finesse (HF) Fabry–Perot cavity equipped with a spacer made from a low-expansion material like ULE or Silicon. Additionally, by well-engineered servo-loop electronics, the laser's fractional frequency instability aligns with the fractional optical-path-length instability of the cavity. Consequently, environmental disturbances like temperature fluctuations or vibrations, which can vary the optical path length of the HF cavity, need to be effectively minimised.

This paper introduces the mechanical and electrical design of an insulation platform that is currently built in our setup of the Calcium ion clock. The inner section surrounds the cavity and consists of a vacuum chamber, where the HF cavity is placed including a passive thermal shield and temperature sensing. It allows the cavity to reach a low-level thermal noise. It provides the HF cavity with stable operating conditions and isolate it from thermal radiation that could affect the cavity dimensions. The outer section consists of a wooden box embedded with insulation foams and elements for insulation of environmental perturbations such as acoustic vibration and temperature noises (Fig.1). The water-cooling scheme with low acoustic noise and mechanical vibrations is important part of the arrangement. It is based on gravitational principle of the cooling water circulation which leads to low-noise laminar flow.

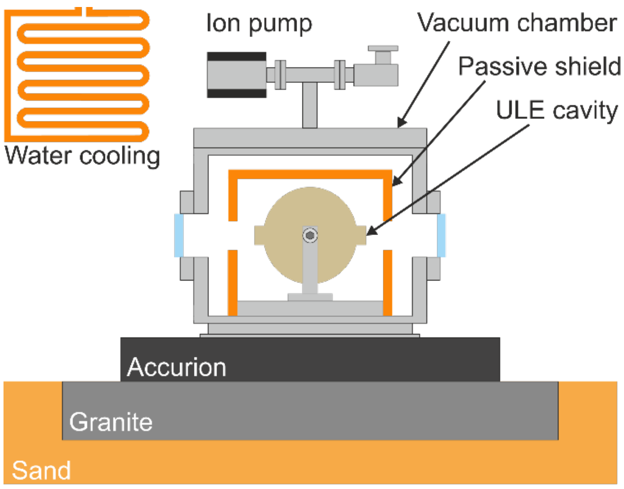

Fig. 1: Schematic of the vibration and thermal isolation platform, including the vacuum chamber and the gold-plated aluminium passive heat shield, centred around the ULE cavity (the shield is temperature-controlled with a Peltier element). The whole setup is then enclosed in a wooden box with thick layers of thermal isolation material.

[1] J. Alnis, A. Matveev, N. Kolachevsky, T. Wilken, Th. Udem, T.W. Haensch, "Sub-Hz line width diode lasers by stabilization to vibrationally and thermally compensated ULE Fabry-Perot cavities", Phys. Rev. A 77, 053809 (2008)