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Using a transportable optical lattice clock for chronometric levelling

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Introduction

The development of optical clocks that can be transported and operated outside metrology laboratories promises exciting new and competitive measurement methods for geodesy, where chronometric levelling is considered as a complementary method to measure height differences [1-4].

To perform such tasks in a competitive way, it is not sufficient to demonstrate the clock performance in the laboratory, but transportable clocks need to show reproducibility of their frequency at the level of few parts in 10^{17} and better in the various locations to which they are transported and where they are used.

At Physikalisch-Technische Bundesanstalt (PTB), we have developed such a transportable optical clock [5] that has been tested for the applications described above by measurement campaigns outside the laboratory. Here we present the latest of these measurement campaigns (Fall 2018) performed at the Max Planck Institute of Quantum Optics (MPQ), discuss the clock´s current uncertainty budget, and recent hardware updates.

Measurements between Braunschweig and Garching

For our recent experiment, we transported the clock to MPQ in Garching (Munich), from where a $\sim$940 km fiber link allowed us to compare the transportable clock's frequency via frequency combs to the ^{87}Sr lattice [6] and Yb^+ single ion [7] clocks in our laboratory at PTB in Braunschweig. Because no other atomic clock at this level of stability and accuracy is available for calibrating the system in the research facility (MPQ), we can clearly demonstrate the use of transportable optical clocks outside the usual metrology laboratory conditions. With upgraded hardware, we improved the clock's uptime shown during the previous campaign, while at the same time reducing the time needed to set it up. The achieved uncertainty is dominated by the systematic uncertainty of the transportable clock of few parts in 10^{17}, corresponding to a few tens of centimeters on the height difference between both sites. The limitation on this uncertainty will be discussed. The height difference between the two locations has also been measured independently with state-of-the art geodetic methods [4].

Results

Through the experiment and results presented in this paper we demonstrate the current status of PTB's transportable clock, in view of reaching a trustworthy reproducibility of its frequency at the low 10^{-17} uncertainty level together with high reliability and uptime during measurement campaigns. We reach this resolution of a few decimeters in height within three hours of integration time. At this level of accuracy, it is in fact possible to perform chronometric leveling measurements, and with further improvements, these may become competitive to classical geodesy methods. We will also our plan to overcome them in view of chronometric levelling measurements at the centimeter level of accuracy.

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