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***Summary*—This work presents the preliminary results of off-line and on-line tests of a robust algorithm for the generation of optical time scales. The algorithm is applied to experimental data from a hydrogen maser and an ytterbium optical clock. The off-line test, where the optical time scale is obtained in post-processing, covers a period of about two months during which the time scale shows a sub-nanosecond accuracy; the on-line test, where the optical time scale is a physical signal obtained in the time laboratory, covers a period of about 1 month and shows an accuracy in line with the results of the off-line test. The future developments of our work, including the integration of the optical clock in the architecture for the generation of the Italian time scale UTC(IT), are also discussed.**

Keywords—time scale; steering algorithm; optical clocks; optical time scale; flywheel oscillator; robustness

I. INTRODUCTION

The unbeaten accuracy and stability reached by optical clocks is paving the way towards a redefinition of the second which could be based on an optical transition, and to the possibility to generate a continuous time scale based on an optical clock, henceforth referred to as an optical time scale (OTS). However, considering that optical clocks are usually only capable of intermittent operation, a practical way to generate a robust and continuous OTS is to use the optical clock as a steering reference for a flywheel oscillator, such as an active hydrogen maser (AHM). The performances which could be reached by an OTS, with a sub-nanosecond accuracy over periods of some months, have been already demonstrated by several recent studies, based both on simulated [1] and real experimental data [2, 3]. In this work we apply the robust steering algorithm proposed in [1] to the experimental data collected at the Italian National Institute of Metrological Research (INRiM), by measuring an AHM with respect to the ytterbium optical lattice clock IT-Yb1 [4]. We present the results of an off-line test, where the OTS is a paper time scale obtained by post-processing experimental data collected over a period of about two months (at the beginning of 2022), and of an on-line test, where the OTS is a physical signal obtained in the laboratory by steering the AHM through a micro-stepper, driven by the steering algorithm running automatically on a dedicated server since December 2022.

Finally, we discuss the future developments of our work, such as the integration of IT-Yb1 in the robust architecture for the automated generation of the Italian time scale UTC(IT) [5], where the optical clock will be used as one of the available frequency steering references within the time scale algorithm presented in [6].

II. STEERING ALGORITHM

The applied steering algorithm has been extensively described in [1], where we distinguished between an original and a refined version, the latter more suited for scenarios with a high up-time of the optical clock. For the tests discussed in this work, where the up-time is still low, we used the original version of the algorithm, so that the main component of the frequency steering correction, Δf_0, is computed by a linear extrapolation based on a batch of past frequency offset data. The total steering correction, Δf, is the sum of Δf_0 and a second component, Δf_2, correcting the residual time offset of the generated time scale with respect to a reference time scale, such as UTC or UTCr.

III. OFF-LINE TEST RESULTS

For the off-line test we used data collected from February to April 2022. During this period IT-Yb1 has been operated for some hours during the working days, so that the days with a measurement are almost the 60% of the total. However, the actual total up-time is lower, about 40%, since each daily measurement lasts only a fraction of a day. Due to the relatively short duration of the test, the Δf_2 component of the steering correction has been computed by using UTCr (new data available once per week) rather than the more stable time reference UTC (new data available only once per month through the Circular T). Fig. 1 shows the accumulated phase offset between UTC and the off-line OTS: the grey line with empty circles represents the time scale obtained by steering the AHM with Δf_0 only, showing a peak-to-peak variation of about 1.5 ns, whereas the red line with dots represents the OTS obtained by steering the AHM with the total correction including Δf_2, exhibiting a similar peak-to-peak variation but also showing the effect of Δf_2 in keeping the OTS phase-aligned to UTC, with a time accuracy at the sub-nanosecond level over the considered two-month period (95th percentile of $|UTC - OTS| \approx 700$ ps).

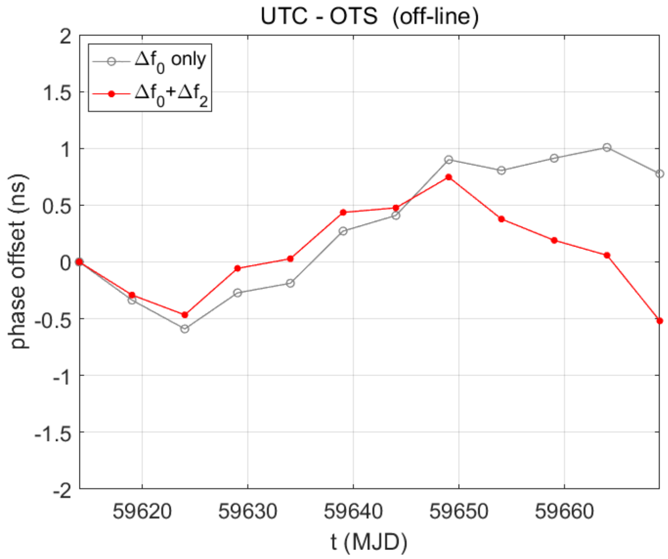

Fig. 1. Phase offset between UTC and the off-line OTS, for a time scale steered with Δf_0 only (grey line with empty circles) and for the one steered with the total correction Δf.

IV. On-line Test Results

For the on-line test we used data collected from December 2022. The preliminary results here presented cover a period of about one month, and the phase offset of the on-line OTS is plotted versus UTCr, as UTC, through the relevant Circular T, is not yet available at the time of writing. During this initial one-month period IT-Yb1 has been operated for a few hours on 10 randomly distributed days, so that the days with a measurement are around the 35% of the total. Fig. 2 shows the accumulated phase offset between UTCr and the on-line OTS. Note that, for this on-line test, the time scale has been obtained by steering the AHM with Δf_0 only. The peak-to-peak variation of the accumulated phase offset versus UTCr is about 1 ns and the time scale does not show any significant drift, therefore the results are in line with those obtained in the off-line test.

V. Way Forward

The results obtained in the preliminary tests described in the present work are compatible, or even better than the results expected from the simulations presented in [1]. While the on-line test is still running, with a new IT-Yb1 measurement campaign expected in the next months, we will proceed with an optimization of the steering algorithm for the low up-time scenarios, giving proper weight to the latest measurements, and with the integration of IT-Yb1 in the robust architecture for the generation of UTC(IT): the optical clock will be used along with the other available steering references, namely the cesium fountain ITCsF2 and UTC/UTCr, in order to improve

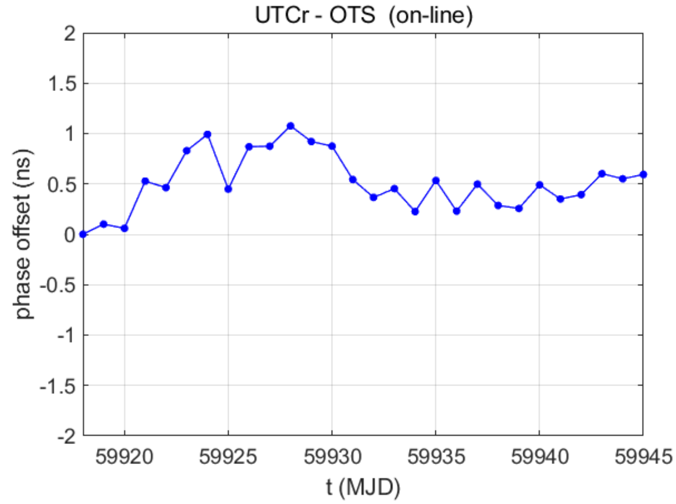

Fig. 2. Phase offset between UTCr and the on-line OTS, for a time scale steered with Δf_0 only.

reliability, stability and accuracy of UTC(IT). In particular, the proper combination of measurements from the intermittently running IT-Yb1 and ITCsF2 clocks will reduce the dead times and hence improve the quality of the steering corrections applied to the master clock, i.e., the quality of UTC(IT).

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