A UTC(NTSC) Steering Algorithm Based on an Atomic Clock Ensemble Scale

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Abstract*—National Time Service Center, Chinese Academy of Sciences(NTSC) has taken the charge of the national standard time UTC(NTSC). The time differences between UTC and UTC(NTSC) has not exceeded ±5ns ever since 2018,which is notable achievements in high precision time-keeping area. The short-term(≤5d) frequency instability of UTC(NTSC) needs to be improved, meanwhile the robustness and accuracy of UTC(NTSC) are also what we want to improve. To achieve this, we modified the timescale algorithm and steering algorithm, which is testified with clock data in our Time-keeping laboratory. Result shows that the time differences between UTC and UTC(NTSC) was always less than 2.5 ns during September 2021, and the frequency instability of UTC(NTSC) is low than 5E-16(5d).

Keywords*—atomic time scale; frequency stability; predictibility; steering strategy;

I. Introduction

NTSC has taken the charge of the national standard time UTC(NTSC), and UTC(NTSC) serves as the basis for NTSC's time service, for local clock comparisons and remote time comparisons. At present, the NTSC maintains an ensemble of about 20 commercial cesium clocks, 13 hydrogen masers clocks. Moreover the remote time transfer links as GNSS CV, GNSS PPP and TWSTFT are used to connect with UTC, thereby high precision international tracebility is realized.

Both H-maser clocks and cesium clocks are the key frequency standards, which the performance of the two types of clocks are familiar to time & frequency experts. During January 2018 to August 2021, UTC(NTSC) has been realized using a H-maser clock and a phase micro-stepper, the difference between UTC and UTC(NTSC) has not exceeded ±5ns, but the local timescale UTC(NTSC) has not good short-term stability. To deal with this shortcoming, and we also want to reduce the absolute time differences between UTC(NTSC) and UTC. we compared the performance and key physics parameters of masers and cesium clocks , then modified time scale algorithm and the steering algorithm, and data analysis and conclusion was finally presented.

II. METHODS/RESULTS

January 2018 to August 2021, UTC(NTSC) has been realized using an active hydrogen maser (AHM) steered in frequency via a phase micro-stepper. As can be seen from Fig. 1, the time differences between UTC and UTC(NTSC) has not exceeded ±5ns from January 2018 to August 2021. As can be seen from Table I and Table II, from the frequency instability results, the 5-day frequency instability of UTC(NTSC) remains at 4E-15, while compared with other countries' local standard time, the 5-day frequency instability has achieved the order of E-16. So the UTC (NTSC) steering algorithm greatly still has the enhanced space.

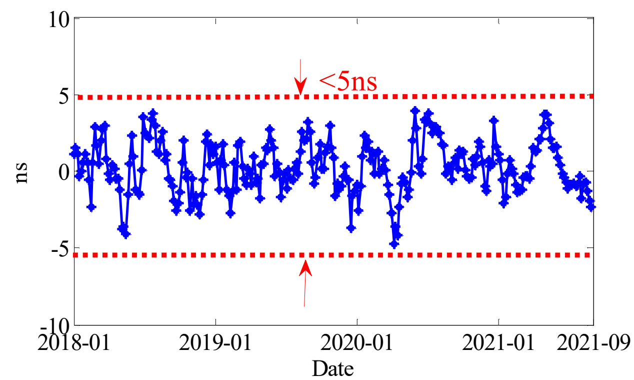

Fig. 1 UTC-UTC(NTSC) (2018.01-2021.09)

TABLE I The frequency instability of UTC-UTC(k)

Average times/d	NTSC	OP	SU	USNO	PTB
5	2.8E-15	7.3E-16	5.3E-16	8.9E-16	8.2E-16
10	2.0E-15	6.1E-16	4.7E-16	5.9E-16	8.2E-16
40	8.7E-16	4.2E-16	3.9E-16	5.6E-16	6.3E-16
80	4.3E-16	3.7E-16	3.6E-16	4.1E-16	2.4E-16

TABLE II The performance of UTC-UTC(NTSC)

Lab	RMS/ns	Maximum Absolute Differences/ns
NTSC	1.7	4.7

From the analysis of UTC(k) steering algorithm of other national time laboratories, it can be seen that, due to the different clock ensemble configuration and the master clock system composition of each laboratory, the frequency steering algorithms of each time laboratory have their own characteristic feature.

In order to improve the synthetic capability of UTC(NTSC), we combined with three factors of our laboratory actual situation, including the atomic clock performance, time scale algorithm, and frequency steering algorithm. Compared with previous researches on UTC(NTSC) steering algorithm, the research process is more detailed.

The performance analysis of atomic clocks is no longer limited to atomic clocks data and indoor temperature of clock room. The monitoring process that the key physics parameters of cesium clocks(see Fig.2) and hydrogen clocks is increased, and the correlation analysis between the physics parameters and the time difference/frequency difference data of atomic clocks is carried out. At the same time, the dynamic Allan variance is used to monitor the real-time performance of atomic clocks(see Fig.3). It can not only quickly detect abnormal conditions, including phase jump, frequency jump et al. The gradual deterioration of atomic clocks performance can also be monitored from the continuous frequency instability results.

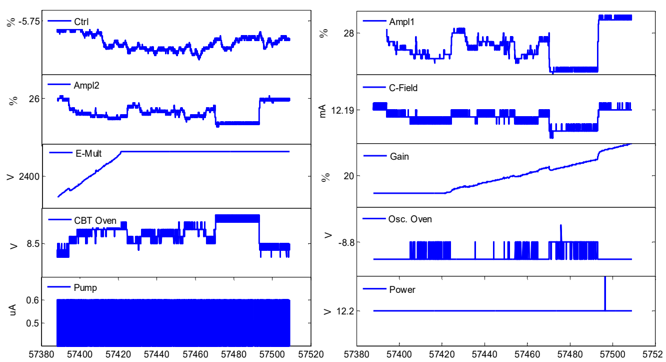

Fig.2 The physics Parameters of a cesium clocks

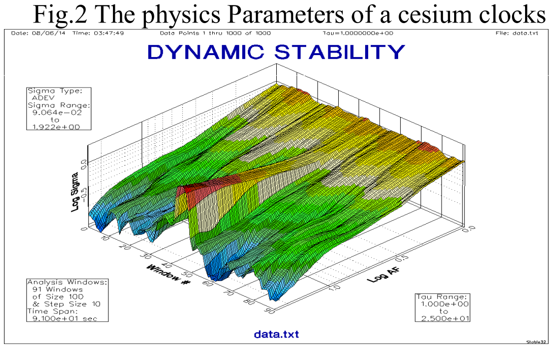

Fig.3 The dynamic Allan variance of an atomic clock

The second point is to modify the time scale algorithm. According to the characteristics of the atomic clock ensemble in the laboratory, the original algorithm is modified to be more suitable for our laboratory. The time scale algorithm has two key points: atomic clock prediction model, weight distribution model. The previous prediction models of atomic clocks are only distinguished by the types of atomic clocks. The prediction model of cesium atomic clocks use linear models and The prediction model of hydrogen atomic clocks use quadratic models. However the improved prediction model uses sliding prediction model and residual term analysis for each atomic clock, the precise mathematical modeling of each atomic clock are generated. The method of assigning weight model has also changed, with predictive residuals being used to dynamically weight for each atomic clock. Results shows that, the time differences and frequency instability of TA(paper time scale) have been significantly improved(see Fig.4 and Fig.5).

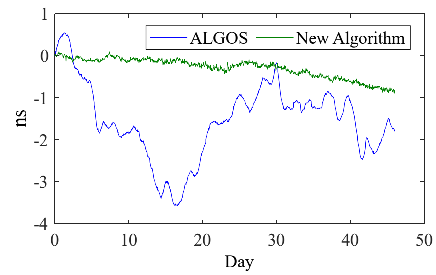

Fig.4 The time differences between TA and UTC(NTSC)

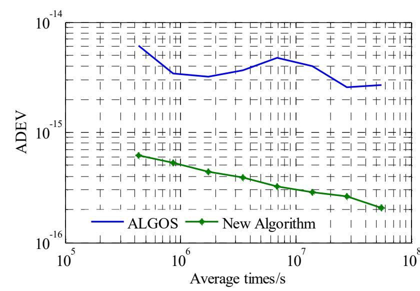

Fig.5 The frequency instability of TA-UTC(NTSC)

The third point is to modify the frequency steering algorithm. We need to think about how we can improve the frequency instability of UTC(NTSC), especially the 5-day frequency instability, under the existing conditions(see Fig.6). Through experiments and data analysis, it is found that the previous steering period is a fixed period, so there is room for improvement of the steering algorithm. At present, the optimal steering theory is adopted to improve the frequency instability of UTC(NTSC) on the premise of ensuring the accuracy of UTC(NTSC).

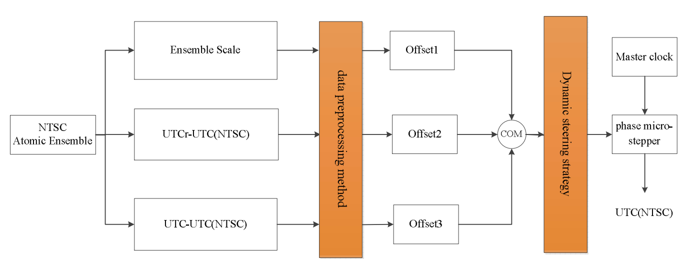

Fig.6 The steering algrithms procedure

III. RESULTS

Finally, UTC(NTSC) works much better than before because of the new algorithms, and the results of UTC-UTC(NTSC) in 2021.09~2022.12 are discussed. Fig.7 shows that the difference between UTC and UTC(NTSC) has not exceeded ±2.5ns based on the new steering algorithm, TABLE III shows the frequency instability of UTC(NTSC) is low than

5E-16(5d) . TABLE IV shows that the RMS(Root-Mean-Square) of UTC-UTC(NTSC) decreases from 1.7 ns to 0. 67ns.

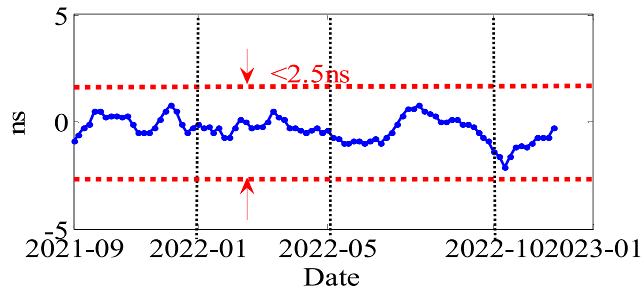

Fig. 7 UTC-UTC(NTSC) (2021.09-2023.01)

TABLE III THE FREQUENCY INSTABILITY OF UTC-UTC(K)

Average times/d	NTSC	OP	SU	USNO	PTB
5	4.8E-16	3.6E-16	3.9E-16	3.7E-16	8.6E-16
10	4.3E-16	3.1E-16	2.2E-16	2.5E-16	4.3E-16
30	2.2E-16	2.2E-16	1.6E-16	2.5E-16	2.7E-16

TABLE IV THE PERFORMANCE OF UTC-UTC(NTSC)

Lab	RMS/ns	Maximum Absolute Differences/ns
NTSC	0.67	2.1

A UTC(NTSC) Steering Algorithm Based on an Atomic Clock Ensemble Scale was studied, experiment platform was established and relevant frequency steering software was done. Results shows that the new algorithms can keep the difference between UTC(NTSC) and UTC within ±2.5ns, and the improvement in frequency instability is obvious.

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