The Hydrogen Maser and Cesium Clocks in Time Keeping at NTSC

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Abstract— **Hydrogen masers and cesium clocks are two important kinds of precision frequency standard, and each of them has its own advantages in time keeping. It is important to investigate the way for effectively combining these two kinds of cocks in order to form a better atomic time scale. There are four hydrogen masers and eighteen Hp5071A cesium clocks at NTSC (National Time Service Center, the Chinese Academy of Sciences). Two of the hydrogen masers are MHM-2010 which is manufactured by symmetricom, and the other two are made in Shanghai Astronomy Observatory (SHAO), the Chinese Academy of Sciences. It is well known that the advantage of a Hydrogen maser is concentrated on its short term stability; however its frequency could drift when it runs for long term. The advantage of a cesium clock is its long term stability; however its short term stability is worse than that of a hydrogen maser. In addition, clocks, even though are of the same kind, their performance could be very different because of their noise and other factors.**

In this paper, the performance of atomic clocks at NTSC is studied through the analysis of their noises. In atomic time scale algorithm, the short term stability and the long term stability of each clock are considered separately, which makes the frequency of time scale more stable for both long and short terms. For calculating the weight of a group of clocks the difference between Allan deviation and standard deviation is discussed in detail.

I. INTRODUCTION

In the late 1980s, as the main time keeping instrument, Hp5061A and Hp5071A cesium clocks have been used in the time keeping system at Nation Time Service Center, the Chinese Academy of Sciences (NTSC). The local UTC was UTC(CSAO) before the year of 2000, and now it is UTC(NTSC). Before June 2004 when we imported the two MHM-2010 Hydrogen masers, only could we analyze the short term stability and long term stability of cesium clocks, so we could not understand the advantages of a Hydrogen maser in practice. The clock data of the time comparison between the master clock of NTSC and the two HMs have been sent to BIPM since October 2004. By using the clock data and that of BIPM Time Section Products, we analyzed the performance of the two Hydrogen masers.

The weights of the two Hydrogen masers that BIPM calculated are very small[1]. One of them is always 0.001, and another one is nearly 0. From the weight one could easily think that neither of the Hydrogen masers is good in stability. However as we know the short term stability of a Hydrogen maser is better than that of a cesium clock, further when BIPM calculate the weight of a clock the long term stability of EAL is mainly taken into account[2]. In order to clarify the advantage of a cesium and a hydrogen maser, it is necessary for us to analyze the two kinds of frequency standard thoroughly.

When a time laboratory calculates their local atomic time scale, an important step is to determine the weights of the atomic clocks, whereas there are several different deviations could be used when determining the weights, among which standard deviation and Allan deviation are the most two important ones, but the difference between those when determining the weights should be taken into account.

II. HYDROGEN MASERS AND CESIUM CLOCKS AT NTSC

Because different atomic clocks will differently contribute to the local atomic time scale, it is necessary to analyze the noise of a clock, through that one can know the performance of the clock clearly. The clock data of the time comparison between the master clock(MC) and one of the clocks is expressed as UTC(NTSC)-Clock(i), and i is the number of clock. For a clock, its phase white noise could be obtained by subtracting the moving average from its original clock data. The MC of NTSC system consists of a frequency source (atomic clock), a micro phase stepper and a digital clock. Each device has its own phase white noise. If σ_1, σ_2 and σ_3 are the standard deviation of main clock, micro phase stepper and digital clock respectively, the total classical variance of the white phase noise in the clock data is[3][4]:

$$\sigma_{TOTAL}^2 = \sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \sigma_{TIC}^2 + \sigma_i^2 \qquad (1)$$

Where σ_{TIC} and σ_i are the contribution of the time interval counter and clock i. There are eighteen cesium clocks, two Sigma τ hydrogen masers and two SHAO hydrogen masers at NTSC. We analyzed two of them as followings. Fig.1 shows the phase white noise of MC-H227 and MC-Cs1016.

The data used for the analysis covered the period Oct 1, 2004 (MJD=53279) to Sept 1, 2005 (MJD=53614), during which some devices were updated. It is evident that different devices would bring different noise levels to the clock data of

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time comparison. The white phase noise of H226 is much smaller than that of Cs1008, which can be seen obviously around the MJD=53434 when the frequency source of MC was changed from a cesium clock, Cs1008, to a maser, H226. The change of the noise level can also be seen around MJD=53541 on which the micro phase stepper was updated from TST 6490A to SDI HROG-5. Fig.1 (A) and Fig.1 (B) shows the distinct difference of the noise level between H227 and Cs1016 after MJD=53434. That is to say, the noise of H227 is much smaller than that of Cs1016. the standard deviation σ_{TOTAL} of [MC-H227] and [MC- Cs1016] after MJD 53541 is shown in table 1.

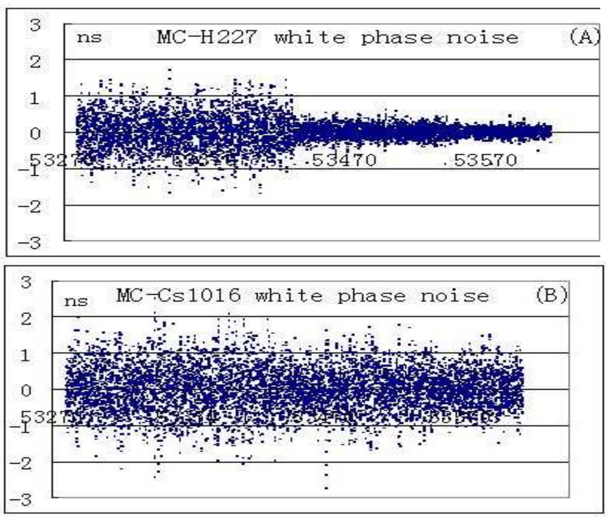

Fig.1 phase white noise of [MC- Clock(i)] for a maser (H227) and a cesium clock (Cs1016)

TABLE.1 TOTAL NOISE OF MC-H227 AND MC-CS1016

Clock number	σ_{TOTAL}
H227	***0.10***
Cs1016	***0.50***

A data series could be obtained by calculating the difference of the clock data between the adjacent 24 hours, namely $y_{(mc\text{-}clock)}(t,\Delta t) = (MC-clock)_{t+\Delta t} - (MC-clock)_t$,called day difference, where Δt =24hours, to show the frequency variation of the MC-clock. In order to get a more stable time scale as a reference to analyze the frequency stabilities of different atomic clocks, an ensemble time scale could be simply made with the equal weighted average of MC-clock(i). We used the data MC-clock(i) of 7 cesium clocks to get the time differences between MC and the time scale TA'(7Cs), MC- TA'(7Cs). The data series of day difference $y_{(TA'(7Cs)-clock)}(t,\Delta t)$ are therefore obtained. Fig (2) (A) and (B) shows the data of $y_{(mc-H227)}(t,\Delta t)$ and $y_{(TA'(7Cs)-H227)}(t,\Delta t)$:

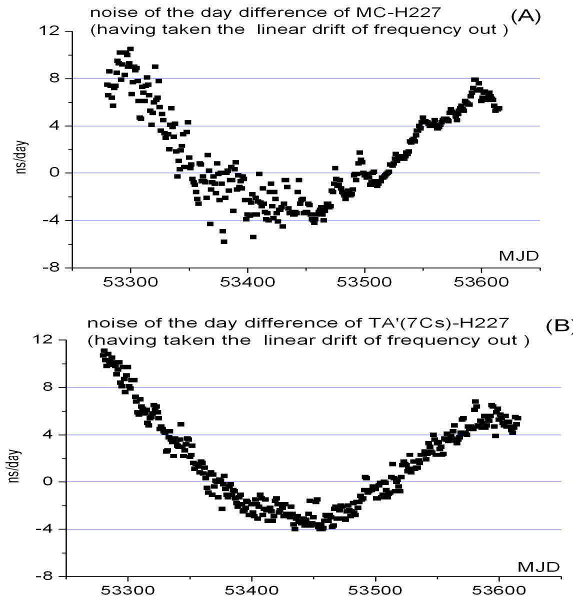

Fig. 2 noise of H227's one day difference calculated from MC-H227 and TA'(7Cs) –H227(The linear drift of frequency have been taken out)

TA'(7Cs) is more stable than any one clock in general, so we can find the long term frequency drift of H227. In (A) of Fig. 2, the obviously different dispersions before and after MJD=53434 is by the frequency source updating. If the long term drift is taken out of the original data, we can find that the short term FM noise of a hydrogen maser (H226 as the frequency source) is much smaller than that of the cesium clock Cs1008.

An example of the phase fluctuations of TA'(7Cs)-H227 and TA'(7Cs)-Cs1016 are shown in fig.3:

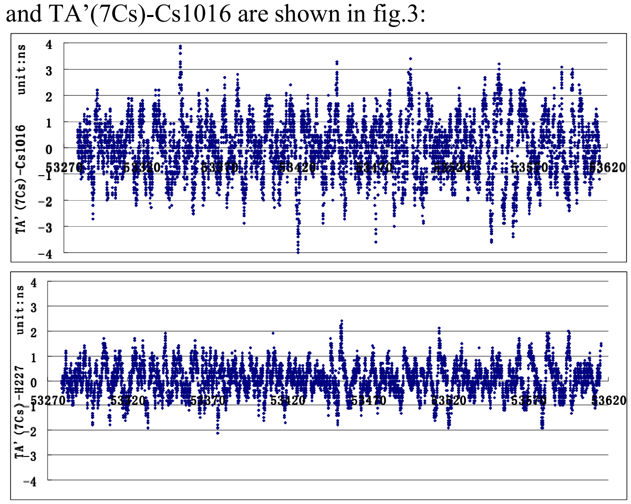

Fig. 3 short time phase fluctuation of Cs1016 and H227

We analyze the real data in the Fig.3, and the short time phase fluctuation is the phase white noise. However, it is evident that the short term stability of H227 is better that that of Cs1016. Though the advantage of a hydrogen maser is in its short term stability, the frequency drift of H226 and H227 are very obvious. As an example, Fig. 4 shows the frequency drift of H227 and Cs1016 with the data of 5 days difference of TAI-clock.

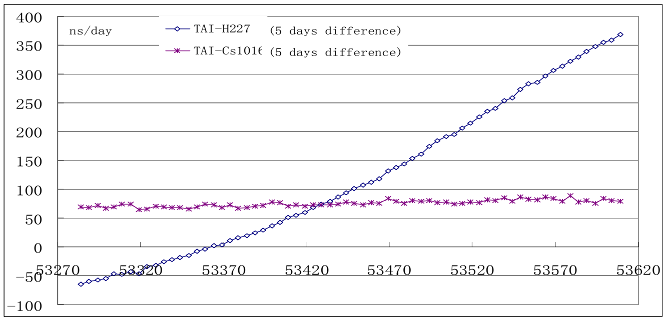

Fig. 4 comparison between H227 and Cs1016 on frequency drift

In order to clarify the difference between those two kinds of clock, we calculate the Allan deviation of them with the reference of TAI and TA'(7Cs). We only select H227 and Cs1820 to show the Allan Dev in Fig.5.

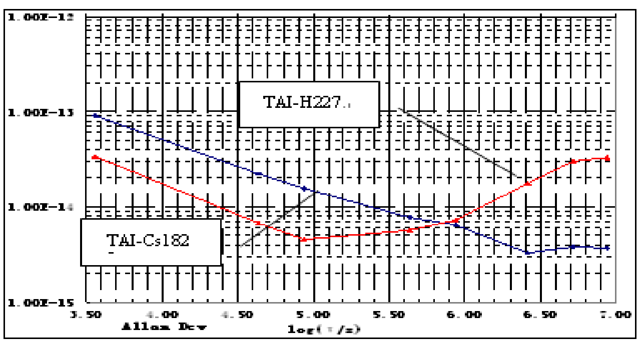

Fig.5 Allan deviation of H227 and Cs1820

The drift which could be modeled with nonlinear (power 2) model has been taken out of the original data. The references are TAI (τ>=5days) and TA'(7Cs) (τ<5days).

III. CONSIDERING THE LONG TERM AND SHORT TERM STABILITY IN TIME KEEPING

Both long term stability and short term stability must be considered in time keeping. As a time laboratory who provides the standard time to users it should keep its |UTC-UTC(k) | <100ns, the smaller the better[5]. For BIPM the long term stability is mainly concerned, but for a time laboratory, not only the long term stability should be kept in well status, but also the short term stability should. In general, users other than time keeping always concern the short term stability at first, such as the users who works on device synchronization and frequency calibration.

Because the short term stability of a hydrogen maser is better than that of a cesium clock obviously, we should use a hydrogen maser as the frequency source of MC, furthermore, monitor and steer the frequency of UTC(NTSC) with the reference of the local atomic time which is calculated with the data of the cesium clocks[6].

In order to improve the short term stability of local atomic time, we could take the hydrogen maser as the reference, and use wavelet filter to reduce the White PM noise[7]. When we use the H227 as the reference, and the result is shown in figure 6:

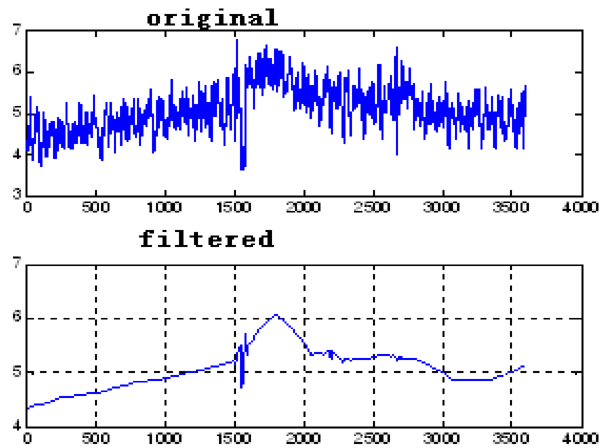

Fig. 6 original data and filtered data of H227

We also could take the average of a group of cesium clock as reference, and fit the hydrogen maser data, furthermore eliminate the frequency drift.

After decreasing the short term noise of Cesium clocks and long term frequency drift of hydrogen masers, the new local atomic time TA'(NTSC) can be calculated. The figure 7 shows the result of Allan dev of TAI-TA(NTSC) and TAI-TA'(NTSC).

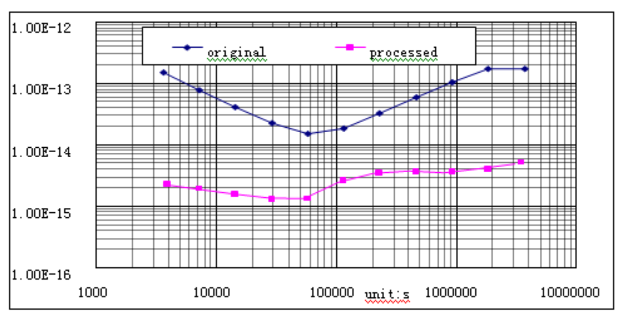

Fig. 7 the stability of TAI-TA(NTSC) and TAI-TA'(NTSC)

IV. CONCLUSIONS

Knowing the performance of a group of clocks is necessary, which can help an engineer who works on time keeping make full use of clocks, and take the full advantages of each clock, such that the long term stability of a cesium clock and the short term stability of a hydrogen maser could both play important roles in the time scale calculation. For the same kind of clocks, it is also necessary to clarify their performance, in order that a time laboratory could choose the best clock as the frequency source and MC and the other usage.

A hydrogen maser has the advantage of excellent short term stability. Taking it as the reference of cesium clock, we could filter the noise of cesium clock. Before a hydrogen maser is used in the atomic time scale calculation, its long term frequency drift must be eliminated.

ACKNOWLEDGMENT

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