Performance of Hydrogen Maser and Its Usage in Local atomic time at NTSC

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Abstract: **The advantage of a hydrogen maser is in its short-term stability, however, with the same hydrogen masers, their performance are different. In 2004, four hydrogen masers were bought to time keeping laboratory of NTSC, two of which were made in USA, and the other two in China. In order to make full use of the hydrogen masers, it is necessary to study their performance which includes the short-term stability, long-term stability, noise, frequency drift etc. Through the exhaustive study and analysis one could exactly know their different performances, and consequently different methods could be studied when they participate in the calculation of local atomic time (TA).**

In this paper, the performances of the four hydrogen masers are discussed with the emphasis on the two hydrogen masers made in America, by analyzing the data which are obtained from the time comparison system at NTSC, and then the method of how to use them in the calculation of TA(NTSC) is studied. By using the method, the short-term stability of TA(NTSC) increases obviously.

Keywords: **hydrogen maser; stability; atomic time**

I. Introduction

When calculate the local atomic time, the performance of an atomic clock should be known clearly. As we know, the long-term stability of a cesium clock is better than that of a hydrogen maser, but the short-term stability is inversely. For BIPM the long-term stability of a clock is mainly considered when calculating the EAL, however the quantity of atomic clock does not exceed 20 for a time laboratory (except the USNO), so it should make full use of each atomic clock which it hold when calculating the local atomic time. That is to say, the performance of each clock in the laboratory must be known clearly.

As there are some evident differences between a cesium clock and a hydrogen maser, the application of them should be considered separately in the calculation of local atomic time. In June 2004 two Hydrogen masers, MHM-2010, were imported at NTSC from America. Having been running steadily two years, their performances were analyzed by using the comparison data.

II. The noise theory of an atomic clock[1]

The core of an atomic clock is its frequency source. Atomic clock is a close kind of frequency origin, however there is an evident difference between the real time T_1 and its ideal time $T(t)$:

$$T(t) = T_1 + x(t) \quad (1)$$

where $x(t)$ represents the time difference. $x(t)$ is affected by the character of an atomic clock in which includes noise and is frequency drift.

In 1971, the power-law spectral model of an oscillator was put forward systematically by Barnes and etc. The noise of an atomic clock could be thought as the integration of five different noises:

$$z(t) = z_{-2}(t) + z_{-1}(t) + z_0(t) + z_1(t) + z_2(t) = \sum_{\alpha=-2}^{2} z_\alpha(t) \quad (2)$$

$z_\alpha(t)$ is the different noise with the vary value. For α=-2, $z_\alpha(t)$ means random walk FM, α=-1, flicker noise FM, α=0, white noise FM, α=1, flicker noise PM, α=2, white noise PM. Formula (2) express the relation of the different noise and the total noise, however their statistical model are determined by power-law density function:

$$S_y(f) = h_{-2}f^{-2} + h_{-1}f^{-1} + h_0 f^0 + h_1 f + h_2 f^2 = \sum_{\alpha=-2}^{2} h_\alpha f^\alpha \quad (3)$$

where h_α (α = -2,-1,0,1,2) are constant which denote the value of different noise. For different atomic clock, h_α should use different value. When calculating an atomic time scale, a laboratory always pays its attention to the component of phase time, formula (4) has proved:

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$$S_x(f)=\frac{1}{(2\pi f)^2}S_y(f) \tag{4}$$

From (4) and (5), it is easy to get the power-law spectrum of phase time:

$$S_x(f)=\frac{1}{(2\pi)^2}(h_{-2}f^{-4}+h_{-1}f^{-3}+h_0f^{-2}+h_1f^{-1}+h_2)=\frac{1}{(2\pi)^2}\sum_{\alpha=-2}^{2}h_\alpha f^{\alpha-2} \tag{5}$$

The power-law spectrum of phase time has become a useful method to analyze the noise of a clock, but we can not obtain its real power-law spectrum for a noise process. In fact, only can we do is to estimate it from the discrete data.

III. The stability of Hydrogen masers at NTSC

As it is known, the short-term stability of a hydrogen maser is higher than that of a cesium clock. There are four hydrogen masers at NTSC, marked as H226, H227, H445 and H446. In order to know their characters of noise and frequency drift, we analyzed them separately. By using the comparison data, which generated every second, the short-term stability of them was analyzed. Figure.1 shows the Allan deviation of the four hydrogen masers, and the reference is the average of 17 cesium clocks with equal weight.

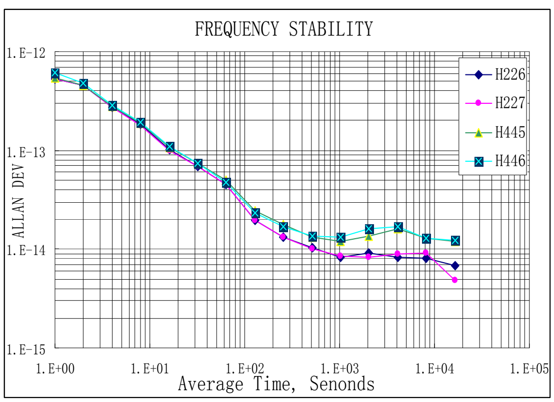

Figure. 1 Allan deviation of the four hydrogen masers

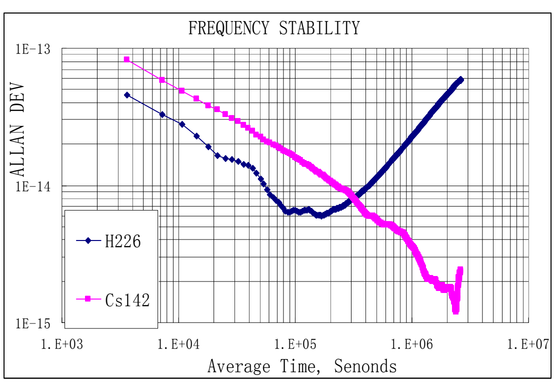

Figure. 2 the comparison of H226 and Cs142 in stability

Figure 2 shows the stability of a hydrogen maser and a cesium clock marked as Cs142 from an hour to 30 days. As we have known, when the sample interval τ is shorter than a day, the stability of hydrogen maser H226 is higher than that of the cesium clock Cs142, and when τ is longer than a day, the stability of H226 is lower than that of Cs142.

For a hydrogen maser, if its long-term frequency drift could be taken out from the raw data by a fit model, the long-term stability of the time scale based on it should be improved. We take H226 for an example. In the example the reference is TA(17Cs) which is the average of 17 cesium clocks with equal weight. Figure 3 shows the raw data of TA(17Cs)-H226. A conclusion could be made form Figure. 3 that there is a stable frequency drift of H226. If an appropriate model x(t) could be calculated, the stable frequency drift could be taken out, then the long-term stability of the calculated time scale based on H226 must be improved.

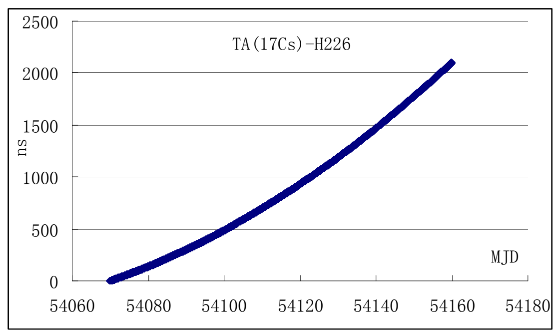

Figure. 3. the raw data of TA(17Cs)-H226

According to the data, a model of TA(17Cs)-H226 can be obtained, $X(t)=0.000206t^2+0.5295t-0.3536$. If taken out the X(t) from the raw data, Figure.4 can be obtained:

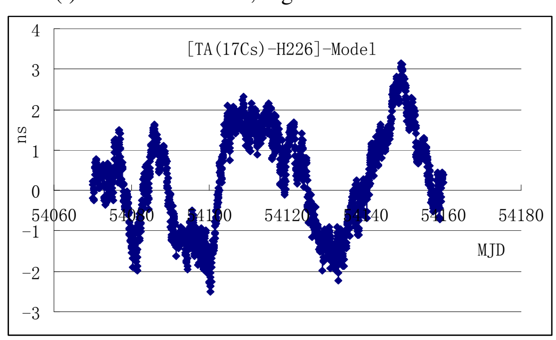

Figure 4. TA(17Cs)-H226 without long-term frequency drift

When take the long-term frequency drift out of the original data, the stability of the time scale based on H226 is shown in Figure. 5:

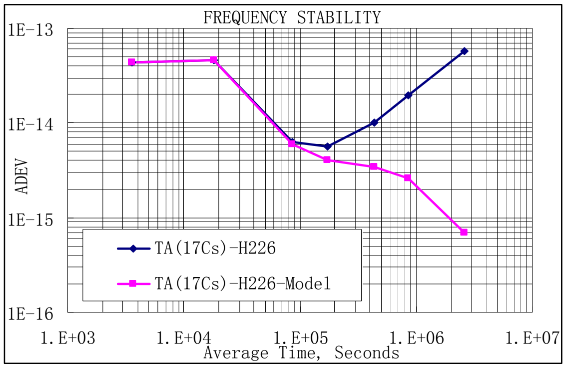

Figure.5 the stability of time scale based on H226 in different situation

When BIPM calculate the EAL the long-term stability， τ =20 to 40 days, is mainly taken into account. Because the long-term stability of a hydrogen maser is far less than that of a cesium clock in common, the weight of a hydrogen maser is always very little. For BIPM it could use almost all the best clock in the world, so it is not necessary for them to analyze every clock especially the long-term frequency drift of hydrogen maser, but for a time laboratory, it needs indeed.

With the dynamic frequency drift estimation, in which parabolic fit is used to the data of every two past months of TA(6Cs+2Hm)-H226 and TA(Cs+2Hm)-H227 and the resulted linear frequency drifts are applied in and removed from the data of the two hydrogen masers for the current month, we calculated a time scale TA(6Cs+2Hm) with 6 cesium clocks and 2 masers. The Long-term stability of the time scale is improved evidently as compared with another time scale TA(8Cs) which includes 6 same cesium clocks as TA(6Cs+2Hm) for the same period data of 2006. Fig X shows the comparison. The results are shown in Figure 6:

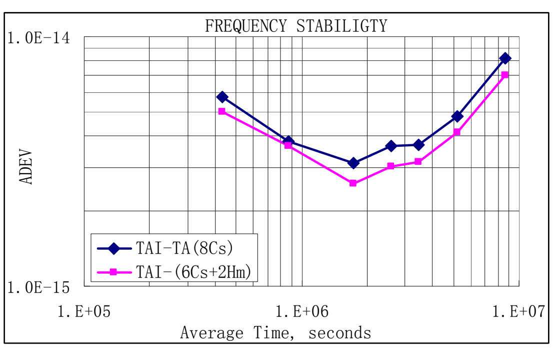

Figure6. the stability of different time scale

IV. Eliminating the noise of an atomic clock signal

For a time laboratory not only the long-term stability but also the short-term stability is important. The importance of its long-term stability is self-evident; however the application on short-term stability is very much, such as the calibration of a device and an instrument. So it is necessary to improve the short-term stability of a clock.

As it is known, the short-term fluctuation of a clock is mainly brought by white noise PM and flicker PM which can be found in the Typical Sigma-Tau Pattern Figure.7.[2][3] So if the noise of PM could be eliminated or reduced, the short-term stability must be improved.

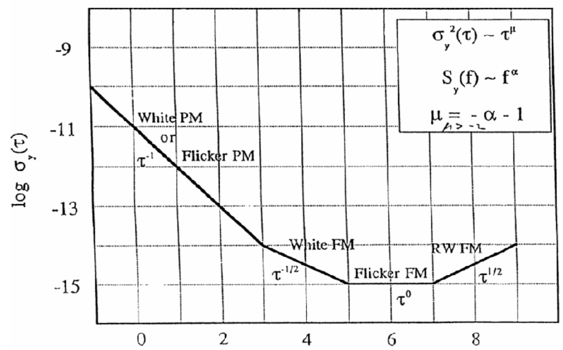

Figure.7 Typical Sigma-Tau Pattern

There are so many digital filters which could be used in the noise eliminating, that it is necessary for us to determine which one is the best selection. The methods of Two-Stage Least-Squares Regression(TSLSR), Wavelets, Auto Adaptation(AA), Homeostasis(H), Median Value(MV), Kalman, and Vondrak are discussed here. Wavelets transform has the character of multiresolution, and it could be use to analyze the part performance of a series signal in both time domain and frequency domain with fixed windows in size and variable form, so it is suitable to detect the noise in the normal signal. x(n) denote the UTC(NTSC)-CLOCK data whose linear drift in frequency has been taken out, and it can be written as [4][5]:

$$x(n) = (x_1, x_2, \cdots x_n) = s(n) + e(n) \qquad (6)$$

where s(n) is the effective signal, e(n) is the noise. s(n) corresponds the low frequency part in frequency domain; and e(n) expresses high frequency part in frequency domain. In this paper, we take cesium clock Cs1016 for an example to discuss the difference when uses the different filter methods. The data used in this section are UTC(NTSC)-Cs1016 and the date is from 1Sep, 2006 to

31 Oct, 2006(MJD: 53979~54040). The raw data of Cs1016 is shown in Figure. 7:

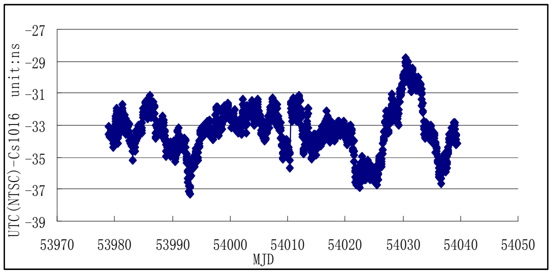

Figure.7 the raw data of UTC(NTSC)-Cs1016

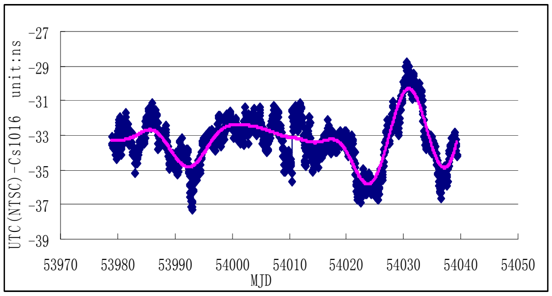

Figure.8 wavelet smoothing

After smooth the signal of Cs1016 by other methods, the RMS and Allan deviation (τ=1 day) of them were calculate, and the results are shown in table1:

Table.1. Allan deviation and RMS of different method

	ALLAN DEV	RMS
wavelet	1.81E-15	1.149
vondrak	2.50E-15	1.263
kalman	3.98E-15	1.307
H	9.54E-15	1.389
MV	1.12E-14	1.407
AA	1.15E-14	1.412
TSLSR	1.17E-14	1.416
RAW	1.92E-14	1.469 (STDEV)

From the table1, it is evident that the RMS and Allan deviation are all improved. Compared with the other methods, the wavelets method is the best one according to the result of table1. The same conclusion can be obtained for τ <1 day.

V. Conclusions

According to the result of just discussed when laboratories calculate the local atomic time(TA), in order to improve the long-term stability of their TA and make full use of the advantages of their atomic clock, it is necessary for them to study the performances especially its Hydrogen maser in details.

As for the short-term stability of TA, a time laboratories can use a digital filter to improve it. According to the result of section IV, the wavelets filter is the best selection.

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