An Improvement of TA(TL): Using the Combination of a Hydrogen Maser And a Cesium-Clock Ensemble

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***Abstract*—we developed a model to predict and modify the long term behavior of a hydrogen maser. We found the 1st order phase difference of a hydrogen maser, relative to TA(TL), was roughly homogeneously increased by time in whole analyzed period. Base on it, we modeled the frequency offset of a hydrogen maser as a linear function of time, remove the frequency drift and get modified phase combined the TA(TL) with a hydrogen maser. We examined the modified phase data by IGS GPSCP time transfer final data. The results showed the modification did not affect the short-term and mid-term stability; its Allan deviation is almost the same as the original hydrogen maser when the average time is under 3 days. We also found the longer period we used the better long-term performance we got, the periods of 30, 50, and 100 days showed comparable stability to TA(TL) when average time is more than 10 days.**

I. Introduction

The TL's local atomic time scale, TA(TL), was announced in October 2004. Currently, it's generated from a 9-cesium-clock ensemble. The stability of TA(TL) is limited by the number of cesium clocks in the ensemble and we knew it's roughly proportional to $1/\sqrt{N}$, where N is the total number of clocks. To improve the performance of TA(TL), we now consider adding hydrogen masers into our clock ensemble. The aim of this paper is to find a model to predict and modify the long term behavior of our hydrogen masers, and may try to use it to generate a new time scale model.

After analyzed the phase data of clocks in TL, we found the first order time difference of the hydrogen maser, relative to TA(TL), was roughly homogeneously increased by time in whole analyzed period. Since the first order time difference can be treated as the average frequency during each two phase measurements, we supposed the frequency of the hydrogen maser could be modeled by a linear function of time. The parameters of the linear function could be predicted from the first order time difference between a hydrogen maser and TA(TL) in a previously period. We thought this treatment could optimize the hydrogen maser for long term stability with respect to TA(TL). Here we calculated the parameters using long-term durations of 10, 30, 50, and 100 days, and used the parameters to remove the frequency drift of the hydrogen maser linearly. Finally, we examined the modified data of the hydrogen maser by IGS GPS carrier phase time transfer final data.

The results showed the modification did not affect the short-term and mid-term stability; its Allan deviation is almost the same as the original hydrogen maser when the average time is under 3 days. We also found the longer period we used the better long-term performance we got, the periods of 30, 50, and 100 days showed comparable stability to TA(TL) when average time is more than 10 days.

II. Data Analyzing

We first analyzed the data of a hydrogen maser and our cesium-clock ensemble time scale, TA(TL). In this paper the hydrogen maser HM6052 was chosen to be analyzed, because it's running independently. Another hydrogen maser (HM6053) was locked by HM6052 with cavity auto turning.

From Figure 1, we found the minimal value of Allan deviation (HM6052 vs. TA(TL)) was about 4.5e-15 (average

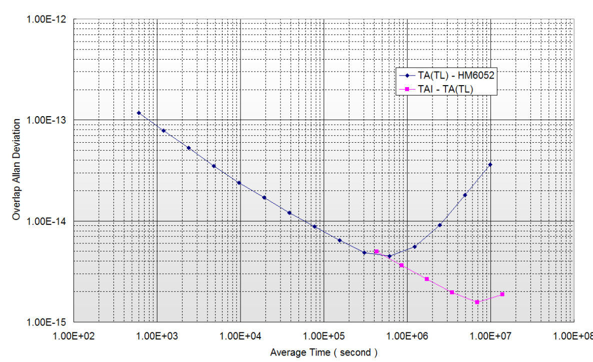

Figure 1. The Allan Deviation of TA(TL)-HM6052 (*Blue dot*) and TAI-TA(TL) (*Pink dot*)

time = 7 days). On the other hand, the minimal value of Allan deviation of TA(TL), compared with TAI, was about 1.5e-15 (average time = 80 days). The HM6052 is an active hydrogen maser (model type: Kvarz CH1-75), we know its minimal value of Allan deviation is about 1e-15 when average time is about 1 day and, from our measurement system, the 1 day Allan deviation of TA(TL) - HM6052 is about 8e-15. Thus we infer that the TA(TL) is noisier than HM6052 when average time is less than 7 days. Beyond 7 days, the accelerate frequency drift will deflect the phase of HM6052 from the linear way.

Figure 2 showed the phase data of TA(TL) – HM6052 from MJD 53500 to MJD 54100. It's obviously the curve is not linear. That's it's not easy to use a linear function to predict the phase behavior of a hydrogen maser.

To analyze that variation of the phase data, we calculated its 1st order difference:

$$d_i(t) = x_{i+1}(t) - x_i(t) \qquad (1)$$

Figure 3 is the result of equation (1).

In the first impression of Figure 3, the tendency of the 1st order phase difference looks like to be linear increase in whole analyzing period. The measurement system of TL records each clock's phase data once per 10 minute. That's each point of Figure 3 meant the 10 minutes average frequency offset of each recording time. We instinctively think the frequency offset of HM6052, with respect to TA(TL), is stationary increase by time and could be modeled by a optimized linear function.

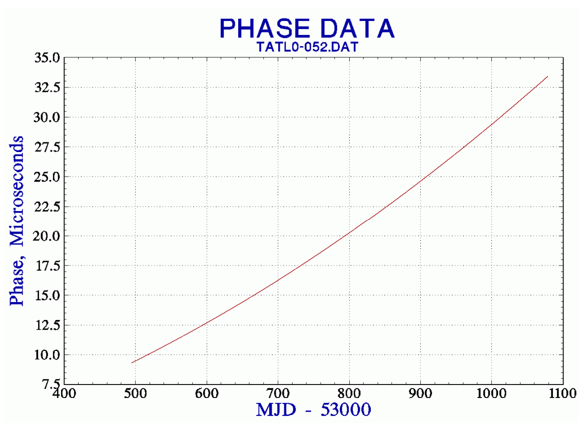

Figure 2. The phase of TA(TL) – HM6052

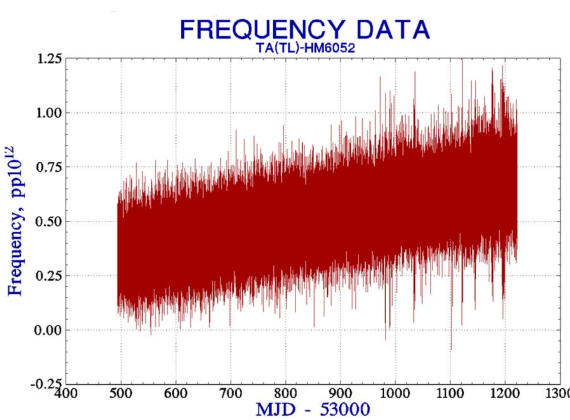

Figure 3. 1st order phase difference of TA(TL) – HM6052

If the frequency offset was roughly homogeneous increase by time, the slope of the frequency offset would be steady in a long term average. We calculated the average slope of the frequency offset of each day using least square linear fit method:

$$S_p(mjd) = Slope\ of\ [d(mjd\text{-}period) \sim d(mjd)] \qquad (2)$$

Where S_p (S_{10}, S_{30}, S_{50}, and S_{100}) denoted slope, calculated by least square linear fit, of the frequency offset during the previous period date mjd – 10 days, mjd - 30 days, mjd - 50 days, and mjd – 100 days to the date mjd.

The graph plot of S_{10}, S_{30}, S_{50}, and S_{100} were showed in Figure 4. The variation of S_{10} was relative large, and the longer period using for average, the more stable slope value we get. The standard deviation of S_{100} was about 2e-14 ns/10 min/10 min.

Since the TA(TL) is more unstable than HM6052 when the average time is less than 7 days, the fluctuation in Figure 2 could be due to the noise of TA(TL). We supposed the slope $S_p(mjd)$ we got from the least square linear fit method can represented the frequency drift of HM6052 with respect to TA(TL). Rationally, the time integration of the $S_p(mjd)$ should be the phase drift of HM6052 optimized by TA(TL). Thus we modified the origin phase of HM6052 by the phase drift:

$$T_p(t) = HM6052(t) - (t_0 + S_p(mjd) \times t + 1/2 \times S_p(mjd) \times t^2) \qquad (3)$$

Where $T_p(t)$ denoted the phase of modified hydrogen maser time scale in time t, and the $S_p(mjd)$ is the slope of the 1st order phase difference of TA(TL) – HM6052 we calculated from equation (2). Figure 5 showed the phase of T_{10}, T_{30}, T_{50}, and T_{100}. Compared with Figure 2, it's obvious that the drift of frequency of HM6052 was removed and long term behavior is followed the linearity of TA(TL).

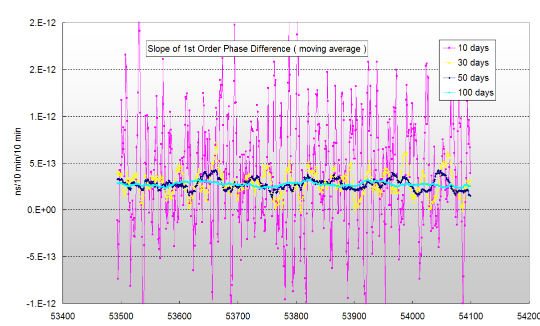

Figure 4. Slope of 1st order phase difference; 10, 30, 50, and 100 days average

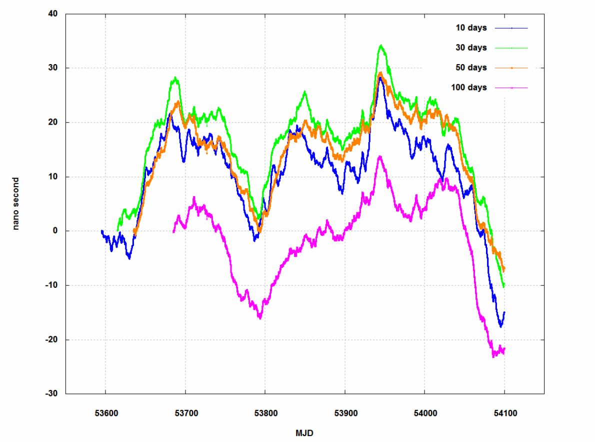

Figure 5. The modified phase of HM6052, T_{10}(blue), T_{30}(green), T_{50}(orange), and T_{100}(pink)

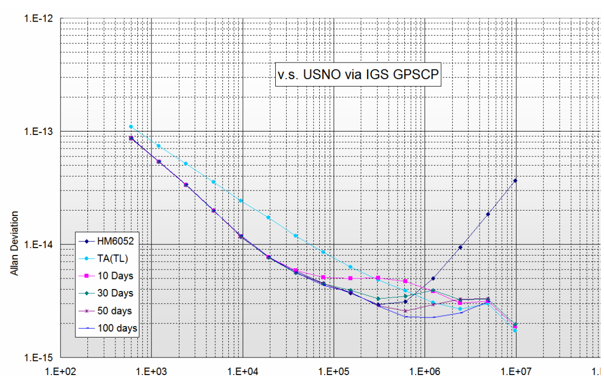

Figure 6. The Allan deviation of HM6052, TA(TL), T_{10}, T_{30}, T_{50}, and T_{100} with respect USNO via IGS GPSCP

III. RESULT

To verify the performance of $T_p(t)$, we used the IGS GPSCP finial data to exam our result. We chose the IGS site USNO as our reference because the Circular T gave the long term reference (more than 5 days) only. We calculated the phase difference USNO – TWTF directly from the IGS GPSCP finial data. The reference clock of IGS site TWTF is UTC(TL), and than get the time difference USNO – T_p :

$$USNO - T_p = (USNO - TWTF) + (UTC(TL) - T_p) \qquad (4)$$

Where the UTC(TL) – T_p = (UTC(TL) – HM6052) + (HM6052 – T_p)

The modified phase of HM6052 showed very good performance when compared with USNO. In Figure 6, T_{10}, T_{30}, T_{50}, and T_{100} all kept the stable short term of hydrogen maser and accurate long term of TA(TL). In the short term performance, 10, 30, 50, and 100 days average period almost have the same stability with HM6052. We also found the long term Allan deviation decrease if the average period of T_p increase. The T_{100} showed the best long-term properties, we guessed it's because of the TA(TL) has the minimal value of Allan deviation when the average time is longer 80 days.

IV. CONCLUSIONS

To enhance the performance of the time scale TA(TL), we have to increase the number of clock in our cesium ensemble. Now we can enhance the short term stability by the combination of hydrogen masers and the cesium-clock ensemble. But in this moment, TL has only two hydrogen masers, and locked together by Cavity Auto Turing, use only one hydrogen maser to generate TA(TL) may take a lot of risk, the damage or fail of hydrogen maser will crush the TA(TL).

Today the modified phase of hm6052 is a reference time scale using for adjusting the UTC(TL). We are planning to buy 2 more hydrogen masers, and will renew the model of TA(TL) at that time.

REFERENCES

[1] Allan D. W. [1987] Time and Frequency (time domain) characterization, estimation, and prediction of precision clocks and oscillators. IEEE trans. Ultrasonics. Ferroelectrics and Frequency Control, UFFC-34, 647-654.

[2] ITU [1997] Handbook selection and use of precise frequency and time system, Chapter 6.

[3] Azoubib J., Granveaud M. and Guinot B. [1977] Estimation of the scale unit duration of time scales. Metrologia, Vol. 13, 87-93.

[4] Tavella P. and Thomas C. [1991a] Comparative study of time scale algorithms. Metrologia, Vol. 28, 57-63.

[5] Lin S. and Peng H. [2003] A paper clock model for cesium clock ensemble of TL. 35th Annual Precise Time and Time Interval Meeting, 2003.

[6] Lin S [2004] A Phase Locked Mechanism for Time Scaling Frequency Control System. 2004 IEEE International Ultrasonics, Ferroelectrics, and Frequency Control Joint 50th Anniversary Conference, 2004.

[7] Lin S., Peng H, Tseng W., Lin H., Liao C. [2004] The Future Model of TA(TL), 36th Annual Precise Time and Time Interval Meeting, 2004

[8] Lin S., Peng H, Tseng W., Lin H., Liao C. [2005] An Improvement of the Controlling Algorithm for Taiwan's Time Scaling System, 2005 Joint IEEE International Frequency Control Symposium and Precise Time and Time Interval Systems and Applications Meeting, 2005.