Chinese Astronomy and Astrophysics 42 (2018) 279–290

CHINESE
ASTRONOMY
AND ASTROPHYSICS

Research on the Method of Noise Error Estimation of Atomic Clocks† ⋆

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Abstract The simulation methods of different kinds of noises of atomic clocks are given. The frequency flicker noise of atomic clocks is studied by using the Markov process theory. The method for estimating the maximum interval error of the frequency white noise is studied by using the Wiener process theory. Based on the operation of 9 cesium atomic clocks in the laboratory of time and frequency primary standards of NTSC (National Time Service Center), the noise factors of power-law spectrum models are estimated, and the simulations are carried out according to the corresponding noise models. Finally, the maximum interval error estimates of the frequency white noises generated by the 9 cesium atomic clocks are acquired.

Key words astrometry: time, atomic clock, noise, methods: data analysis

1. INTRODUCTION

The operation of atomic clocks is of great significance for the time-keeping service, for which the error analysis of atomic clocks is necessary. The atomic clock errors are divided into two parts: definite deviation and random noise. The definite deviation can be compensated by the model prediction, while the intensity of random noise is generally estimated with the Allan deviation or the power-law model of noise, then based on the noise intensity, the

† Supported by Project of Open Foundation of National Key Laboratory of Geographical Information Works (SKLGIE2014-M-1-3)

Received 2016-09-10; revised version 2016-11-22

⋆ A translation of *Acta Astron. Sin.* Vol.58, No.3, pp. 19.1–19.10, 2017

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doi:10.1016/j.chinastron.2018.04.007

corresponding noises are simulated by means of statistical analysis, and for the frequency white noise the confidence limit for the different time intervals and different confidence levels can be determined through the Wiener process theory [1], which appears as a statistical method of maximum error estimation. Besides, the algorithm of atomic time also needs to know the noises of atomic clocks, in order to reduce the corresponding noises according to needs. For the noise simulation method, in Reference [2] the frequency flicker noise is generated from the white noise by using a noise model filter with a certain transfer function, which has used the double linear variation, this leads to a large quantity of calculation and a low accuracy. Reference [3] simulated the frequency flicker noise by means of power-series summation of random uniform distribution sequence, in which all the previous sampling must be used, and this leads to a large quantity of calculation, too. In this paper, the frequency flicker noise is simulated using the Markov process, which has a wide application in the various fields of natural science, engineering technology, and economic management. This paper attempts to estimate the noise errors of atomic clocks by means of the Markov process with convenient and linearized calculations.

2. CLOCK ERROR MODEL: THE DEFINITE AND CHAOTIC PARTS

$x(t)$, the time error of atomic clock, is approximately shown as the time difference in phase between a certain atomic clock and a frequency standard or time scale of higher frequency stability. It is simulated by using $x_m(t)$, including a chaotic part $x_0(t)$ and a definite part (see Equation (1)), the latter takes the time error, frequency error and frequency drift of the atomic clock into consideration.

$$x_m(t) = a^k + b^k + \frac{1}{2}c^k t^2 + x_0(t)\,, \tag{1}$$

in which the superscript k means the interval of uninterrupted calculation of the frequency primary standard or time scale; for each interval, a means the time error, b means the frequency error, and c means the frequency drift. There are different a^k, b^k, c^k and chaotic part $x_0(t)$, including a relatively complete noise model, which is shown as the summation of 5 noise processes, and generally expressed by the spectral density function $S_x(f)$ of phase noises, the spectral density function exhibits a quick divergence from the smooth part to the low frequency part. These 5 kinds of noises can be also expressed by the frequency spectral density $S_y(f)$. The intensity of each kind of noise is denoted by h_α, and the 5 kinds of noises include the phase white noise ($\alpha = 2$), phase flicker noise ($\alpha = 1$), frequency white noise ($\alpha = 0$), frequency flicker noise ($\alpha = -1$) and frequency random walk noise ($\alpha = -2$). The particular expressions of spectral density function are given as follows:

$$\begin{aligned} S_y(f) &= \sum\nolimits_{\alpha=-2}^{2} h_\alpha f^\alpha\,, \\ S_x(f) &= \sum\nolimits_{\alpha=-2}^{2} \frac{h_\alpha f^{(\alpha-2)}}{(2\pi)^2}\,. \end{aligned} \tag{2}$$

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