Noise Sources Evaluation of Compact Optically Pumped Cesium Beam Atomic Clock

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***Summary*—The short-term frequency stability of compact optically pumped cesium beam atomic clock is directly affected by signal-to-noise ratio of its Ramsey spectrum. In this paper, the noise sources of compact optically pumped cesium beam atomic clock are analyzed. On the basis of the parameters in our optically pumped cesium beam atomic clock, the noise contributions of different sources within 1Hz bandwidth are studied, and the corresponding signal-to-noise ratios are calculated. According to the evaluation results, one of the main noise sources of the compact optically pumped cesium beam atomic clock is the frequency noise of the detection laser.**

Keywords—Noise sources; CBT clock; laser; frequency; SNR

I. Introduction

Compact cesium beam atomic clocks still play important roles in the field of time and frequency [1]. One of the key performances of compact cesium beam atomic clocks is their short-term frequency stability [2]. The better the short-term frequency stability that compact cesium beam atomic clock has, the more weight they can have in an atomic clocks group. At present, the short-term stabilities of compact cesium beam atomic clocks are between E-11 and E-12 [3-6], and have not entered the E-13 level. Compared with active (E-14) and passive hydrogen maser (E-13) [7], the short-term frequency stability of cesium beam atomic clock is poor. That means the frequency stability of cesium beam atomic clock can play a role only on a long-term averaging time. Therefore, improving the short-term frequency stability of cesium beam atomic clock is an important research direction. The short-term stability of compact optically pumped cesium beam atomic clock is:

$$\sigma(\tau)=\frac{1}{\pi}\frac{\Delta\omega}{\omega_0}\frac{1}{\mathrm{S/N}}\frac{1}{\sqrt{\tau}} \quad (1)$$

It can be seen from the Eq. (1) that when the central transition frequency (ω_0) remains unchanged, the short-term frequency stability is mainly determined by the linewidth ($\Delta\omega$) and signal-to-noise ratio ($\mathrm{S/N}$) of the Ramsey signal. Long primary optically pumped cesium atomic clock [8-10], cold atomic fountain clock [11-12] and cold atomic cesium beam atomic clock [13-15] improve short-term frequency stability by reducing the linewidth of the Ramsey spectrum. As for commercial compact cesium beam atomic clock, the only way to improve the short-term frequency stability of atomic clock is to promote the signal-to-noise ratio.

In this paper, we will show the evaluation processes and the results of noise sources of the compact optically pumped cesium beam atomic clock.

II. Evaluations

A. *Evaluation of laser frequency noise*

The frequency noise of detection laser will directly affect the fluorescence of signal. The frequency noise of laser mainly comes from the inherent linewidth of laser itself. We have following assumptions:

- The center frequency of the laser is the same as the center frequency of the transition line.
- Ignore the deterioration of laser frequency noise generated in the process of laser frequency stabilization.
- Ignore the laser amplitude noise.
- Ignore photon shot noise

We can find out from [16] that:

$$\left(\frac{S}{N}\right)_{laser}=\frac{1}{2}\varphi\sqrt{\frac{2\Omega^2+\Gamma(\Gamma+\gamma_L)}{3\Gamma+\gamma}} \quad (2)$$

Where,

$$\varphi=\frac{1}{\gamma_{L\sqrt{\Gamma}}}\cdot\sqrt{\left[2\Omega^2(3\Gamma+4\gamma_L)+\Gamma\left(\frac{3\Gamma+\gamma}{2}\right)(\Gamma+2\gamma_L)\right]} \quad (3)$$

$\Gamma$is the coefficient of the spontaneous emission, $\gamma_L=2\pi\Delta\nu$ is the line width of the laser and Ω is the Rabi frequency which depends on the laser power.

B. *Evaluation of atomic shot noise*

Atomic shot noise is associated with the fluctuation of the atomic beam flux. In this part, we consider the noise under two assumptions:

- The distribution of the atoms in the atomic beam from the cesium oven is obeyed the Poisson distribution.
- The velocity of the atoms from the oven is obeyed the Maxwell distribution.

we can know from [2, 16, 17] that the atomic shot noise is only depend on the intensity of the atomic beam (ϕ_a):

$$\left(\frac{S}{N}\right)_{atom} = \frac{1}{2}\sqrt{\frac{\pi\phi_a}{2}} \quad (4)$$

C. *Evaluation of other noise*

There is detected noise, un-pumped atomic beam noise and microwave frequency noise. All of these noise sources above are less than atomic shot noise and laser noise.

III. DISCUSSION

According to the above noise evaluation results, we can get the following noise table

TABLE I. EVALUATIONS OF NOISE SOURCES IN THE COMPACT OPTICALLY PUMPED CESIUM BEAM ATOMIC CLOCK

Noise Sources	**Signal-to-Noise Ratio**
Laser frequency	≈7500
Atom shot	≈40000
Detected	>E10
Un-pumped	>E6
Microwave	>E5

We can see that in the current miniaturized optically pumped cesium beam atomic clock, the laser frequency noise caused by the detection laser is the main source of noise.

Therefore, an important way to further improve the short-term stability of optically pumped cesium beam atomic clock is to use narrow linewidth external cavity semiconductor laser to replace DFB laser. In this process, we need to solve the problem of long-term frequency locking of external cavity semiconductor lasers.

IV. CONCLUSIONS

In this paper, we analyze the noise sources of the compact optically pumped cesium beam atomic clock, and evaluate their contribution to the signal-to-noise ratio of the optically pumped cesium beam atomic clock. It is concluded that laser frequency noise is an important factor limiting the improvement of frequency stability of commercial optically pumped cesium beam atomic clock. At present, DFB laser is widely used in many commercial atomic clocks. We guess that the frequency noise of laser is also an important noise source in other miniaturized atomic clocks. Automatic frequency stabilization and long-term frequency stabilization of external cavity semiconductor lasers are important technologies that need to be developed in commercial clock field. Our next work will focus on the application of high-performance lasers.

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