Performance Optimizations Of Optically Pumped Cesium Beam Frequency Standard

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***Abstract*—Because of the excellent long-term stability of cesium beam atomic clocks, they are widely used in the field of punctuality. The research of cesium beam atomic clocks is to optimize and improve their stability gradually. In order to improve the stability of our optically pumped cesium beam atomic clock, we have optimized the circuit system in the atomic clock, including the microwave source and other circuits. Compared to the result in 2020 year, the final stability has been improved by nearly 30%. It shows that circuit noise is an important source which affects the signal-to-noise ratio in compact optically pumped cesium beam clocks. It is necessary to consider and reduce the influence of circuit noise in the design and manufacture of atomic clocks.**

***Index Terms*—Cesium beam clock, optically-pumped, stability**

I. Introduction

In the field of punctuality, the optically pumped cesium beam atomic clock is still not as mature as the magnetic selected cesium beam atomic clock, such as $5071A$. Due to the characteristic of higher atomic utilization and low complexity of beam system design, the optically pumped cesium beam atomic clocks are expected to obtain larger signal-to-noise ratio and better stability than magnetic selected cesium beam atomic clocks. Researches in other groups [1]–[3] show that the stability limit of optically pumped small cesium clocks is approximately $1 \times 10^{-12}/\sqrt{\tau}$. The result is obtained using DFB(distributed feedback) laser and this achievement is even better than those cesium beam clocks using ECDL(external cavity semiconductor laser) [1]–[4].

In 2020, we have presented an optically pumped cesium beam frequency standard with $3.02 \times 10^{-12}/\sqrt{\tau}$ stability [5] which is about three times better than $5071A$ High performance [6]. Now, after some optimizations of circuit system, the short-term stability of our optically pumped cesium beam clock reached $2.17 \times 10^{-12}/\sqrt{\tau}$. The result is approximately four times better than $5071A$ High performance. We got the result using DFB laser.

A key factor affecting the short term stability of cesium beam atomic clock is signal-to-noise ratio:

$$\sigma\left(\tau\right) = \frac{\Delta\omega}{\omega_0}\frac{1}{S/N}\frac{1}{\sqrt{\tau}} \tag{1}$$

where $\Delta\omega$ is and ω_0 is the line width and the center frequency of Ramsey signal. $\sigma\left(\tau\right)$ is the Allan deviation at τ. and There are many researches on the sources of the signal-to-noise ratio in compact cesium beam atomic clocks. Paper [7] summarized that the noise sources are composed of atomic shot noise, laser noise, photon noise and detected noise:

$$\frac{S}{N} = \frac{S}{\sqrt{N_{photos}^2 + N_{atoms}^2 + N_{laser}^2 + N_{detected}^2}} \tag{2}$$

In addition to the physical part, the circuit part is also a source of noise in optically pumped cesium beam atomic clocks. The circuit system in the cesium beam atomic clock can be divided into two parts: microwave source and control system. There are many researches on microwave sources [8]–[10]. The purity of microwave spectrum and phase noise will affect the stability of atomic clocks. There are hardly any researches on control systems. The noise brought by this part of the circuits also participates in the signal-to-noise ratio of the cesium beam atomic clock. Recent improvement in stability is owe to the circuit system.

II. Circuit system of cesium beam atomic clock

There are many circuit boards in an optically pumped cesium beam atomic clock. According to their functions, we can divide them into microwave source circuit boards and control circuit boards and others.

The main functions of microwave source circuit boards contain generate a low phase noise 10 MHz output signal from an OCXO(oven controlled crystal oscillator) and obtaining a 9192 MHz microwave source by frequency multiplication and synthesizer. The signals are the clock signals actually. The quality of this part represents the quality of the clock. The microwave source is one of the main technique in atomic clock researches. Therefore, what researchers can do is to promote the quality of the microwave source continuously. There are mainly the following indicators to measure the quality of the microwave source. They are the purity of the microwave spectrum, the phase noise of the microwave signal, the stability of the microwave frequency, the stability of the microwave power and the frequency and power control precision.

The control circuit boards have many similar functions. They mainly control the parameters in optically pumped cesium beam atomic clock. Compared with magnetic selected

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cesium beam atomic clocks, optically pumped clocks have additional circuit boards related to laser and collections of the fluorescence signal. The quality of the control system affects the stability of the operating parameters in the atomic clock directly. They affects the stability of the final output signal.

The other circuit boards are those who are not directly related to the normal atomic clock operation, such as the power sources, signal monitoring and alarm system, man machine interaction module and wiring board. The part is indispensable in a complete atomic clock. The circuit boards of this part seem to have no effect on the stability of the atomic clock. But due to the connection characteristics of the circuit system, the noise on this part will also affect the signal-to-noise ratio of the atomic clock.

III. Improvement of circuit system

The improvement of the circuit system we did can be divided into two aspects: one was the improvement of the microwave source and the other was the optimization of the structure and interconnections between the circuit boards. The short-term stability was improved by nearly 30%.

A. Improvement of microwave source

The improvement of the microwave source is mainly reflected on the power stability and phase noise. The fluctuation of the microwave power brings many frequency shifts to the output of cesium beam atomic clock. And the microwave source is very sensitive to the environment. Therefore, the stability of the microwave source affects the stability of the atomic clock. In the original case, the signal output from the microwave source was fed into the separated oscillating field directly. And the microwave power is served and locked in a suitable position in the long term operation process. The method presupposes that the power of the microwave source was stable enough during the servo interval. We made two improvements. First, we added a temperature compensation element to the output of the microwave source. It reduced the temperature sensitivity of the microwave source. Second we monitored and compensated the power of microwave signal during the interval of the servo. The phase noise of the microwave source were very relevant to the performance of the oscillators and phase locked loops. The loop circuits needed repeated adjustment. we added a DRO(dielectric resonator oscillator) in the source. And it greatly improves the far end phase noise of the microwave source. The combination of these two improvements make the microwave circuit better.

B. Overall system optimization

In old designed circuits system, Our main concern is the convenience for measuring and monitoring the signal. There are a large number of connectors and connecting lines in the clock. The connections in the circuit system are parallel or interleaved, which invisibly brings the possibility of unwanted loops and interferences.

The design of the new circuit boards removed the redundant connection wires as much as possible. Some necessary connections are realized through the PCB directly. After adjustment, all circuit boards are fixed on a circuit board full of connecting wires through slots and they are well connected to the ground. Reasonable electromagnetic shields are mounted on the some circuit boards and the circuit boards are separated in space to reduce the possibility of crosstalk. More important, the newly designed circuits fully consider the isolations between different signals. Each sub-module has independent power and ground. The results of the technique are effective. The signal of the digital circuit will not be connected to the signal of analog signal parts and the noise between different control parameters will not be transmitted. For example, there is a large PWM(pulse width modulation) current in the temperature control of the DFB laser and the huge noise will interfere the current of the laser which will affect the stability of the optically pumped cesium beam atomic clock.

After the new circuit system completed, the fluctuation of the signal is reduced and that means the signal to noise ratio is promoted.

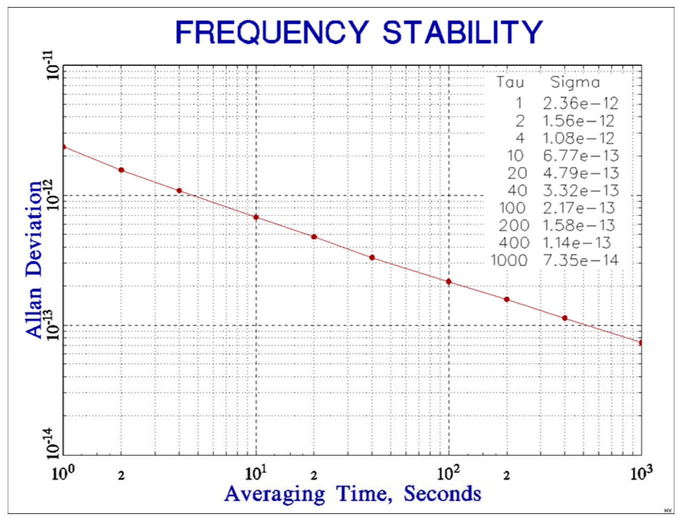

Fig. 1. Allan deviation of the cesium beam atomic clock after optimizations

IV. Conclusion

In general, during the optimization process of optically pumped cesium beam atomic clock, we found that the noise brought by the circuit system affects the overall signal-to-noise ratio of the atomic clock. And sometimes this part of the noise is difficult to find and reduce. It is necessary to fully consider the distribution, interconnection and thermal design of the boards at the beginning. It is important to fully isolate the sensitive circuit components from the other parts. After reducing the noise of the circuit system, the signal-to-noise ratio and the stability of the cesium beam atomic clock is improved from the original $3\times10^{-12}/\sqrt{\tau}$ to $2.17\times10^{-12}/\sqrt{\tau}$ as shown in the figure.1.

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