Performance evaluation of a cesium fountain clock at HUST

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***Abstract*—We have developed a cesium fountain clock (HUST-CsF1) at Huazhong University of Science and Technology (HUST). It is used for realizing the time and frequency traceability of the National Precise Gravity Measurement Facility (PGMF). We have evaluated the frequency stability and systematic uncertainties of the HUST-CsF1. By comparing with a H-Maser, the stability is evaluated to be $1.9\times10^{-13}/\sqrt{\tau}$. The preliminary systematic uncertainty is evaluated to be 8.8×10^{-16}.**

Keywords—cesium fountain clock, systematic uncertainty, frequency stability.

I. Introduction

Time unit "second" is defined on the unperturbed ground-state hyperfine transition frequency of ^{133}Cs, with $\Delta\nu_{Cs}$ equal to 9,192,631,770 Hz [1]. Cesium fountain clock is the primary frequency standard to realize the definition of the "second". The cesium fountain clock named HUST-CsF1 provides a local time-frequency standard to meet the needs of the time/frequency traceability for gravity measurement standards of the PGMF.

The experimental setup is briefly outlined in Section 2, while Section 3 presents the results of frequency stability measurement and systematic uncertainty evaluation.

II. Experimental Setup

A. Physics package

Figure 1 shows the fountain clock physical package based on a room-temperature microwave Ramsey cavity, standing approximately 2.2 meters tall. Four magnetic shields are mounted on the exterior of the C-field region. The C-field provides a static magnetic field of 144 nT. The lower vacuum chamber, equipped with a 2D-MOT, a 3D-MOT, and a detection region, achieves an ultra-high vacuum level of 1.0×10^{-8} Pa [2]. After pre-cooling with the 2D-MOT, a sample of about 1×10^{9} Cs atoms is further cooled in the 3D-MOT using six laser beams at a wavelength of 852 nm. These cold atoms are then launched vertically upwards with an initial velocity that is around 4.4 m/s.

B. Laser and optics

The optical system of the HUST-CsF1 is shown in Fig. 2. A 850 nm semiconductor lasers (pump laser, Toptica DL Pro) is used for the pump laser. Based on the saturation absorption technology, the laser is locked on the ^{133}Cs 6 $^2S_{1/2}|F=3\rangle\rightarrow6^2P_{3/2}|F=4\rangle$ transition.

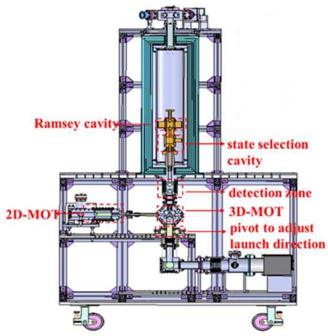

Fig. 1. Sectional view of the HUST-CsF1 physical package

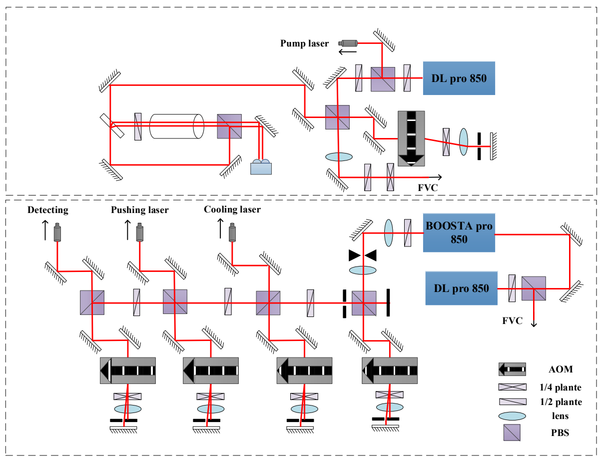

Fig. 2. Schematic of the optical system

Another semiconductor laser (cooling laser) used for laser cooling is locked to the pump laser based on frequency-voltage conversion (FVC) technology. After amplification by a tapered amplifier (Toptica BOOSTA Pro), the laser is used in the setup to generate the required laser beams.

An ultra-low noise fiber laser (precilasers) is used for the 2D-MOT which is locked on the 6 $^2S_{1/2}|F=4\rangle\rightarrow6^2P_{3/2}|F=4\rangle$ transition based on the modulation transfer technology for frequency stabilization.

C. Microwave synthesis

A microwave synthesizer is developed for the setup. The absolute phase noise is measured by a phase noise analyzer

(Rohde & Schwarz FSWP 26), as shown in Fig. 3. The phase noise is -64 dBc/Hz at 1 Hz, limited by the reference H-maser. Based on the absolute phase noise of the microwave synthesis chains, the contribution of the microwave source phase noise (Dick effect) to the frequency stability of the cesium fountain clock is $1.5\times10^{-13}\tau^{-1/2}$ [3].

D. Control system

The program of the electronic control system of the cesium fountain clock is written in LabVIEW. The system has two main functions: control and acquisition. A user-programmable FPGA (NI PXIe-7858) provides multiple channels of analog and digital voltage signals for controlling the MOT magnetic field switch, optical shutter, microwave switch, frequency sweeping for polarization gradient cooling and frequency-shift keying (FSK) of microwave synthesizer

The data acquisition board (PCIe-6351) is used for collecting the Time-of-Flight (TOF) signal during the experiment, which enables frequency discrimination through dual-level detection. The error is servoed to the local oscillator to achieve closed-loop locking of the fountain clock system. Additionally, data acquisition is also used for monitoring some important parameters.

III. EXPERIMENTAL RESULTS

A. Ramsey fringe

The Ramsey fringes obtained are shown in Fig. 4, with a contrast better than 90%. The atomic flight height is approximately 1 meter, and the fringe line width is 0.92 Hz [2].

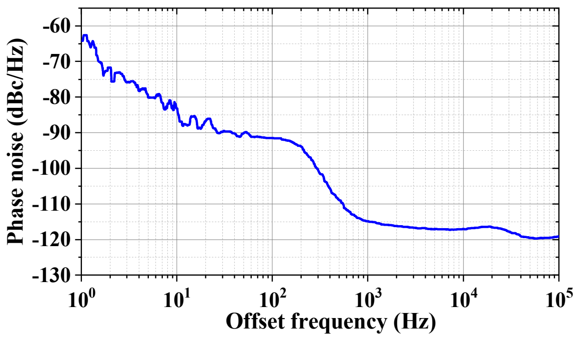

Fig. 3. Measurement results of the phase noise of the microwave synthesizer

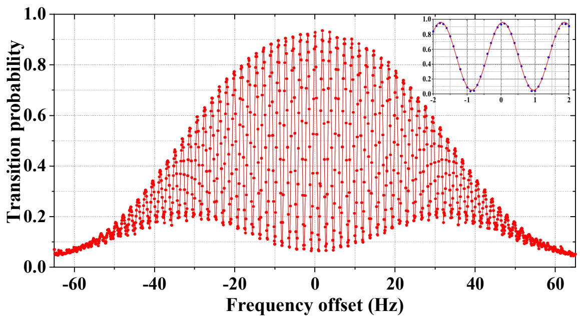

Fig. 4. Ramsey fringe of the cesium fountain clock

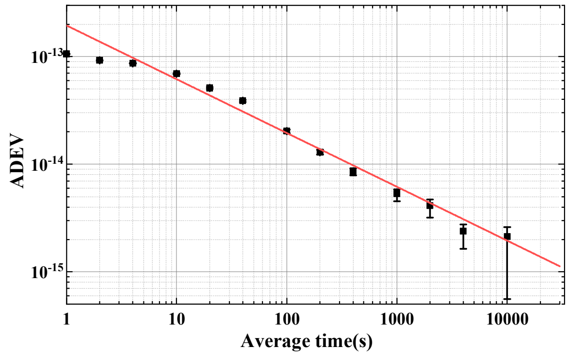

Fig. 5. Stability of the frequency difference between HUST-CsF1 and H-maser.

TABLE I. PRELIMINARY EVALUATED SYSTEMATIC UNCERTAINTIES OF HUST-CsF1

Contribution	**Bias (10^{-16})**	**Uncertainty (10^{-16})**
Blackbody radiation	-190.2	1.4
Second-order Zeeman	1577.2	2.8
Light shift	0.0	0.1
Gravitation redshift	54.2	0.1
Cold collision shift	-44.3	6.6
Background gas collisions	0.0	0.1
Distributed cavity phase shift	-59.8	3.4
Microwave leakage	0.0	3.5
Total	1337.1	8.8

B. Frequency stability

By comparing with a H-Maser (iMaser3000), the stability of the HUST-CsF1 is evaluated to be $1.9\times10^{-13}\tau^{-1/2}$ as shown in Fig. 5. By servoing the error signal to an Oven Controlled Crystal Oscillator (OCXO) , we utilize a frequency comparison device to compare the outputs of the OCXO and the H-maser to obtain the frequency stability.

C. Systematic uncertainty

The preliminary systematic uncertainty of the fountain clock is evaluated to be 8.8×10^{-16} as shown in Table 1.

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