Progress towards accuracy evaluation of NIST-F4 Cesium fountain clock

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We present progress towards accuracy evaluation of the new Cesium atomic fountain[1] Primary Frequency Standard NIST-F4.

NIST-F4 is a molasses-loaded Cesium fountain clock. Two horizontal and a vertical pair of laser beams cool the atoms to approximately 1 μK absolute temperature using polarization gradient cooling and then launch them vertically. The launched cold atom cloud enters an aluminum vacuum tube enclosed by a three-layer magnetic shield. A vertical coil inside the magnetic shields generates a highly homogeneous and stable dc magnetic field using a precision current source.

On the way up, the atom cloud passes consecutively through two cylindrical microwave cavities made of oxygen-free copper with Q-factors of 28,000. The cavities are identical in design and are used for clock state selection and Ramsey interaction, respectively. The Ramsey cavity is driven by four independent microwave feeds that suppress the distributed cavity phase[2] (DCP m=1 and m=2) frequency shifts. After the first Ramsey microwave interaction the atom cloud enters an in-vacuum below-cutoff drift tube connected to the Ramsey cavity. An in-vacuum calibrated PT100 sensor is used to measure the temperature of the drift tube to 0.2 K accuracy. After the second Ramsey microwave interaction, the atom cloud falls through a detection zone below the state selection cavity, where laser excitation and fluorescence detection are used to determine the populations of the two clock states and thus the deviation of the microwave frequency from the atomic resonance.

The fountain microwave synthesizer uses a quartz oscillator referenced to a hydrogen maser using a 100 MHz phase lock loop (PLL). The effective fountain fractional frequency instability for high-density atom cloud fountain operation is $2 \times 10^{-13}/\sqrt{\tau}$, with τ the measurement time in seconds. The fountain control software alternates two frequency servos for high- and low-density cloud operation, as well as a servo for magnetic field measurements. The frequency shift due to cold collisions is inferred from the measured frequency shift between high- and low-density modes and the detected atom numbers. Measurements of the fountain's frequency dependence on the microwave power and vertical tilt alignment, related to DCP frequency shifts, will be discussed. Details of microwave cavity design and four feed operation will be presented. The systematic effects due to the second-order Zeeman, blackbody radiation, and cloud density shifts will be discussed in detail. The DCP-related frequency shifts and the microwave lensing shift are presently under evaluation.

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[1]R. Wynands and S. Weyers, "Atomic fountain clocks", Metrologia 42, S64, 2005.

[2]R. Li and K. Gibble, "Evaluating and minimizing distributed cavity phase errors in atomic clocks", Metrologia 47, 534, 2010.