Accuracy Evaluation of the ACES/PHARAO Laser-cooled Space Atomic Clock

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ACES is a European Space Agency mission that will enable accurate time transfer, precisely test general relativity, and demonstrate a laser-cooled atomic clock in space. ACES will have two clocks onboard, a space hydrogen maser and PHARAO (Projet d'Horloge Atomique par Refroidissement d'Atomes en Orbit),[1] a laser-cooled cesium clock. PHARAO's goals are to reach an inaccuracy of 10^{-16} and a short-term instability of 7×10^{-14} at 1s of averaging. The three largest systematic errors in the preliminary PHARAO accuracy budget are the collisional frequency shift,[2] the distributed cavity phase shift (DCP)[3-6] and the microwave lensing frequency shift.[5-7] We report on the evaluation of these systematic shifts.

The form of the microwave fields in the clock and state selection cavities are needed to evaluate each of these three largest sources of uncertainty. To calculate the fields, we constructed large, densely meshed, three-dimensional finite element models of the microwave cavities.

The DCP frequency shift of PHARAO behaves differently than those of fountain clocks. In PHARAO, microwave power is supplied to both Ramsey interaction zones from a feed in the middle of the two zones. The microwave phase gradients therefore resemble those of a cylindrical fountain cavity that is fed from the top endcap, giving a different signature to the dependence of the DCP shifts on microwave amplitude.

In addition to DCP shifts, we evaluate the microwave lensing shift for PHARAO, applying models in Refs. 5-7. For the long interrogation times in microgravity, microwave lensing shifts are naturally larger than for fountains, of order 1.2×10^{-16}. A tube before the selection cavity gives a circular aperture for the PHARAO clock atoms, and the subsequent apertures of the Ramsey cavity are rectangular, with rounded corners. We treat all of these apertures to calculate the microwave lensing frequency shift. Correcting this shift renders its uncertainty negligible.

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