Improved Accuracy of the NRC-FCs2 Caesium Fountain Clock

Scott Beattie[1], Bin Jian[1], Claude Marceau[1], and Marina Gertsvolf[1]
[1]National Research Council Canada, Ottawa, Ontario, Canada

Email: scott.beattie@nrc-cnrc.gc.ca

Though optical clocks have surpassed fountain clocks in accuracy by two orders of magnitude, caesium fountain clocks retain significance in frequency and time metrology as they currently remain the most accurate primary frequency standards available. As the future definition of the second is being decided, fountain clocks have a key role in ensuring continuity by enabling high accuracy absolute frequency measurements of optical standards; a requirement on the roadmap to the redefinition of the SI second[1].

The NRC-FCs2 fountain clock was first fully evaluated in 2020[2] and has been contributing to the steering of International Atomic Time nearly continuously since then, demonstrating both robustness and accuracy. We continue to work to improve the performance of NRC-FCs2, and have recently re-evaluated the dominant frequency biases to reduce the overall systematic uncertainty. Thus far, we have reduced the uncertainty due to cold collisions[3], synchronized phase transients, and microwave leakage, and are currently finishing the re-evaluation of the distributed cavity phase shift (the four dominant contributions to the systematic uncertainty in NRC-FCs2).

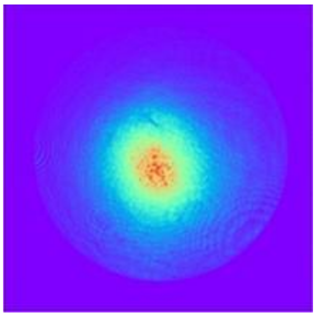

Fig. 1: Absorption image of the atom cloud 60 ms after launch.

Central to the re-evaluation has been the integration of absorption imaging, as shown in Fig. 1, which can be used to determine both the density distribution of the cloud (collisional shift) as well as the trajectory of the atomic cloud (distributed cavity phase shift). Additionally, we have recently developed ultra-stable microwaves by locking a frequency comb to an ultra-stable laser. This has yielded a maximum short-term stability of the fountain of $\sigma_y = 3 \times 10^{-14}\tau^{-1/2}$, which has dramatically reduced the averaging time required for the evaluation of systematic shifts.

We will describe the methods and results of our re-evaluation, which has presently reduced the overall uncertainty below 1.7×10^{-16} in fractional frequency. The reduced systematic uncertainty in NRC-FCs2 will allow for more accurate measurements of the absolute frequency of the $^{88}Sr^+$ clocks[4,5] at the NRC, as well as a more accurate and stable timescale for Canada.

---

[1] N Dimarcq, *et al.*, “Roadmap towards the redefinition of the second”, Metrologia, 61 012001, 2024.

[2] S. Beattie, B. Jian, J. Alcock, M. Gertsvolf, R. Hendricks, K. Szymaniec and K. Gibble “First accuracy evaluation of the NRC-FCs2 primary frequency standard”, Metrologia, 57, 035010, 2020.

[3] S. Beattie and B. Jian, “Characterization of the collisional shift in an atomic fountain clock using absorption imaging”, Metrologia, 60, 045004, 2023.

[4] P. Dubé, A. A. Madej, Z. Zhou, and J. E. Bernard, “Evaluation of systematic shifts of the $^{88}Sr^+$ single-ion optical frequency standard at the 10^{-17} level”, Phys. Rev. A 87, 023806, 2013.

[5] P. Dubé, K. Kato, J. Bernard and B. Jian, "Progress Towards a Transportable and High-Accuracy Sr+ Ion Clock at NRC," 2021 *EFTF/IFCS*, Gainesville, FL, USA, 2021, pp. 1-2, doi: 10.1109/EFTF/IFCS52194.2021.9604288.