Evaluations of PSFS for BIPM Annual Report 2020 - NRC-FCs2 Fountain Clock

The NRC-FCs2 PFS has been reported during 2020 with respect to a hydrogen maser 1400307 (BIPM code). The full evaluation of systematic uncertainties is described in detail in [1], the most recent evaluation, which is the reference listed for the 2020 reports to Circular T and is still up-to-date. Below, we will describe the evaluation of uA , uA/lab and uB/lab, as well as a typical error budget.

Short term stability and type A uncertainty - The typical short term stability of FCs2 for the collisional shift-corrected frequency was 1.7×10^{-13} after 1 second of averaging. The reported values of the type A uncertainty, uA, assume white FM as the dominant noise source during the averaging period. The averaging period is calculated as (reporting period – dead time).

Link to local timescale - The uncertainty of the link with our local timescale, ul_Lab, is the quadratic sum of two terms: the first term is the uncertainty in the frequency transfer between the maser 1400307 and FCs2, and the second term is the result of measurement dead time. In FCs2, the former uncertainty is attributed to phase fluctuations in cables between H-maser 1400307 and FCs2 and is estimated to be no larger than 10^{-16}.

The effects of measurement dead time arise due to both scheduled and unscheduled interruptions in the fountain operation. The unscheduled interruptions were rare, and generally caused by a failure in laboratory environmental control, or a broken laser lock. The contribution of dead time to the uncertainty is estimated using a numerical simulation that models the measurement noise as having two contributions: white FM ($1.7 \times 10^{-13}\ \tau^{-1/2}$) and flicker FM ($4.0 \times 10^{-16}$) [1].

Type B uncertainties - A detailed description of the evaluation of the systematic shifts and associated uncertainties is described in [1]. Table 1 shows a typical error budget, listing the main systematic effects and related type B uncertainties for the period of MJD 59149 – 59179.

Physical effect	Bias [10^{-16}]	Uncertainty [10^{-16}]
Zeeman effect	724.65	0.2
Blackbody radiation	-162.36	0.7
Gravitational redshift	104.52	0.03
Cold collisions	-	3.17
Background gas	-	< 0.1
AC Stark	-	< 0.1
Rabi, Ramsey pulling	-	< 0.1
Cavity pulling	-	< 0.1
Majorana transitions	-	< 0.1
DCP m=0	0.07	0.4
DCP m=1	-0.71	1.3
DCP m=2	0.040	0.2
Microwave lensing	0.60	0.2
Microwave leakage	0.10	1.0
Microwave spectrum	-	< 0.1
Synchronous phase transients	-	0.8
Total	666.9	3.8

Table 1. Contributions to type B uncertainty for FCs2 for period MJD 59149 - 59179. The bias due to cold collisions is corrected actively by toggling between high and low densities and extrapolating to zero.

References:

1. S. Beattie, B. Jian, J. Alcock, M. Gertsvolf, R. Hendricks, K. Szymaniec and K. Gibble, Metrologia, 57 (2020) 035010, DOI https://doi.org/10.1088/1681-7575/ab7c54