Measurements of frequency shifts in a high-performance CPT-based cesium cell atomic clock

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***Summary*— We report on measurements of frequency shifts in a high-performance microwave cesium vapor-cell atomic clock based on coherent population trapping (CPT). The dependence of the clock frequency on numerous experimental parameters, such as the laser power, the laser frequency, the microwave power, the cell temperature, the magnetic field, acousto-optic modulator (AOM) and electro-optic modulator (EOM) temperatures, or the light field polarization is measured. Coupled with the measurement of typical variations of experimental parameters, this study will provide a mid- and long-term stability budget of the clock and will help to identify key contributions to mitigate for improvement of the clock stability after 100 s.**

Keywords*— *coherent population trapping (CPT); atomic clock; frequency shifts; vapor cell; frequency stability

I. INTRODUCTION

Microwave vapor cell frequency standards combine low power consumption, good stability performances and suitability for compactness. They are then attractive candidates to be deployed in a plethora of applications such as communications or navigation systems [1].

In this domain, coherent-population trapping (CPT) was demonstrated to be a competitive approach for the development of clocks with short-term stability levels in the range of a few 10^{-13} at 1 s [2-4], comparable to those obtained with double-resonance continuous or pulsed-optically pumped (POP) Rb clocks [5].

Nevertheless, the stability of CPT clocks is often degraded after 100 s by light-shift effects. To mitigate this contribution, the implementation of composite pulsed sequences, such as the symmetric auto-balanced Ramsey (SABR) technique [6], was demonstrated to be efficient. Indeed, the latter permitted to demonstrate a CPT clock entering the 10^{-15} stability range after a few hundreds of seconds.

Such results, reported in [6], were obtained on limited duration acquisitions. Thus, it is of paramount importance to investigate in detail the sensitivity of the clock frequency to all possible experimental parameters in order to identify major stability contributions, and explore the ultimate performances that such a CPT clock might achieve for mid-long integration times.

II. EXPERIMENTAL RESULTS

Fig. 1 shows a simplified scheme of the CPT clock architecture implemented at FEMTO-ST. The clock combines the push-pull optical pumping (PPOP) interaction scheme [7,8] and a pulsed symmetric auto-balanced Ramsey (SABR) interrogation sequence. The optical bench combines a distributed-feedback (DFB) diode laser, an electro-optic modulator (EOM) modulated by a low-noise local oscillator [9] at 4.596 GHz, a laser frequency stabilization stage using dual-frequency sub-Doppler spectroscopy [10], an acousto-optic modulator (AOM), a Michelson-based stage for producing the PPOP scheme, and a telescope for increasing the beam diameter. The output laser field is sent into a buffer-gas filled Cs vapor cell while the transmitted light, detected by a photodiode, is used by electronics to pilot the clock. The clock short-term frequency stability is measured to be $1\text{x}10^{-13}$ at 1 s in Ramsey-CPT regime, and $2\text{x}10^{-13}$ at 1 s in the SABR-CPT case.

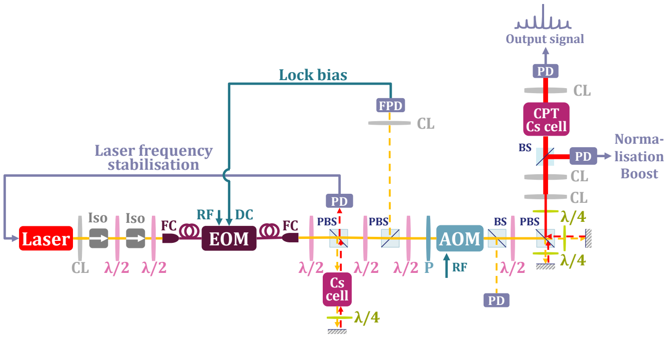

Fig. 1. Architecture of the CPT-based vapor cell atomic clock. CL: converging lens. PBS: Polarizing beam splitter. BS: Beam splitter. FPD: Fast photodiode. PD: Photodiode. Iso: Optical isolator. RF: Radio Frequency. DC: Direct Current. FC: Fiber Optic ferrule connector. P: Polarizer.

Fig. 2 shows the example of a temporal sequence where the clock frequency is changed with steps of the AOM temperature. This allows the extraction of the clock frequency dependence to AOM temperature, shown in Fig. 3. On this curve are identified inversion points where the clock frequency dependence is cancelled at the first-order, yielding locally a function curvature, in fractional value, of about $3\text{x}10^{-12}$ K^{-2}.

Such an experimental approach was repeated for a significant number of experimental parameters, both in Ramsey-CPT and SABR-CPT schemes. The sensitivity to laser power and microwave power were found to be -2.9x10^{-15}/µW and -9.4x10^{-14}/%, in good agreement with results reported in [6].

In addition to “standard” parameters, we have also studied recently the sensitivity of the clock frequency to rotation or translation of key plates or mirrors placed along the clock optical setup. The stability of the light-field polarization at the cell input and its impact on the clock frequency were also explored.

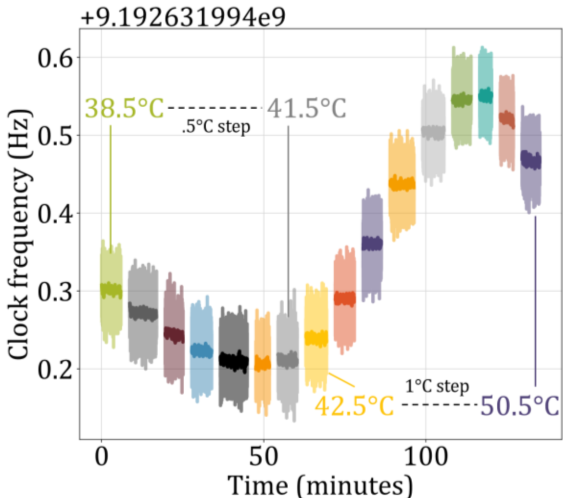

Fig. 2. Change of the clock frequency with 16 steps of T_{AOM}, in SABR-CPT interrogation regime, with T_S = 1 ms, T_L = 4 ms [2].

We will present at the conference the summary of all these sensitivity measurements, and will discuss the contributions to control with precaution, for a stability target of a few 10^{-14} at 1 day.

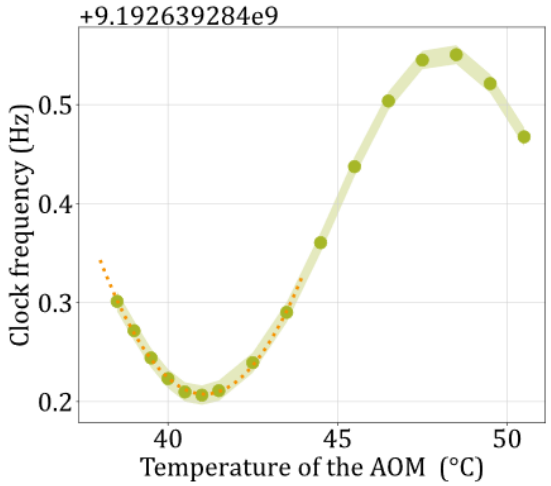

Fig. 3. Clock frequency versus the AOM temperature. Curve extracted from Fig. 2. Inversion points are observed at 41.1 °C and 48.2 °C

III. CONCLUSION

We have explored the sensitivity of the clock frequency on various parameters both in Ramsey-CPT and SABR-CPT schemes. The overall study will allow to evaluate key contributions to the mid-and long-term stability budget of the CPT clock and will indicate key aspects to work on in the future for the improvement of the clock mid-long term stability.

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