THE MULTIPLE VELOCITY FOUNTAIN: A NEW SCHEME FOR THE COLD COLLISION FREQUENCY SHIFT REDUCTION

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In this paper we present an experiment that allows a reduction of the average atomic density of an atomic fountain operation by nearly an order of magnitude without serious reduction of the number of atoms used to generate the atomic reference signal, thus preserving the short term stability performance of the clock.

1 Introduction

In recent years the Cs atomic fountain primary frequency standards have reduced the uncertainty in the realization of the second to the 10^{-15} level. The main frequency shifts in a fountain are connected with fundamental physical phenomena: Zeeman effect, Black body radiation, Gravitational Red shift and collisions between atoms. In a Cs fountain the atomic density is particularly important, because the principal source of uncertainty in the accuracy budget of these frequency standards are due to collisions among cold atoms [1]. In order to reduce the average atomic density in the clock, instead of loading one ball for a long time (few hundred milliseconds) and then launching it, it is possible, in the same amount of loading time, to load several low density balls and launch them at decreasing heights on non-overlapping trajectories. By setting the loading and launching parameters of each ball it is possible to make all the balls overlap only after exiting the Ramsey cavity(in the detection region). Doing so the average density of each ball is kept much lower than in the normally operated fountain [2]. The loading function for the number of atoms n in a molasses is given by the function $n \propto (1-\exp(-t/\tau))$ with typical loading time constants of few hundreds of milliseconds. Several short loading sequences are then relatively more efficient than a single long one. In the multiple velocity fountain (MVF) we load many balls for a short time (20~30 ms), thus launching a high total

number of atoms. Consequently the detected signal of a MVF is of the same order of magnitude as that obtained with traditional fountain single-ball operation.
The Ramsey signal will however be given by the superposition of different Ramsey patterns one for each velocity group.

2 Experimental results and conclusions

We have tested the MVF configuration with respect to the load, launch and detection sequence, the clock transition excitation and detection will be investigated next, several shutters will be needed to avoid the stray light in the Ramsey zone during the loading and launching sequence.
In order to launch many balls to different heights in a tight time sequence, it is necessary to switch the acousto-optic modulator (AOM) frequencies extremely quickly. We have developed a multichannel fast synthesizer [3] based on a Programmable Logic Device (PLD) and several direct digital synthesizers (DDS) operated in parallel that can store long frequency and amplitude sequences for each channel, allowing up to 10 balls to be launched to different heights. The synthesizer can switch from one state to each successive state in less then 1 μs.
The launching sequence we have used in this experiment is: 30 ms load, 1 ms launch, 1 ms post cooling, 10 ms dead time to extract the atoms from the trapping region and then again the same sequence for the next ball with changed launch-frequency parameters. The first ball is launched to 105 cm apogee height while the last one is launched to about 40 cm height. The launching velocity of each ball is set in such a way that the balls all overlap in the detection region.
Figure 1 shows the time of flight signals obtained with 7 balls purposely non-overlapped and overlapped. A comparison between the atom signal obtained from returning atoms with the MVF and with normally operated single ball fountain, loaded for identical (total) loading time, indicates that the expected short term stability should not be degraded by this new technique.
The MVF opens the possibility of reducing the collisional shift in a cesium fountain by nearly one order of magnitude. Since each ball has an independent trajectory and expansion, the contribution of each ball to the accuracy budget has to be evaluated carefully, it is however possible to load each ball for a different time in such a way to optimize simultaneously the short term stability and the total spin exchange shift (more atoms in the highest ball lead to a smaller shift because of a longer expansion time).
Unlike conventional fountain operation, the MVF will show a velocity distribution generated by nearly mono-velocity groups of atoms and, the resulting Ramsey pattern and linewidth are then functions of this velocity distribution. An elegant way to minimize the linewidth-noise transfer to the clock stability is to use phase modulation instead of the more usual square wave frequency modulation [4].

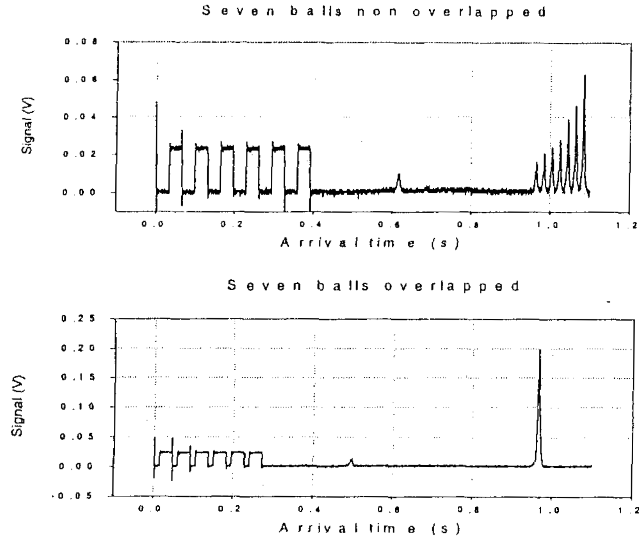

Figure 1 TOF signal obtained with a MVF. a) seven ball non overlapped b) seven balls overlapped in the detection region. The square wave signal is scattered fluorescence light during the loading time.

References

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