Comparative Performance of Compact Schemes of Atomic Beam Longitudinal Deceleration Designed for Space-Based Frequency Standards

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Space-based frequency standards are probably the most important parts of any global navigation system. Optical frequency standards demonstrating the unique stability are extremely promising for space applications. Nevertheless, the stringent requirements to these applications force us to look for simpler technical solutions; among these, the radiofrequency standards using cold atom beams seem to have the greatest potential, and one of the solutions involves the use of CPT-Ramzey resonance optical detection[117].

Since the sensitivity of any scheme of registration of radio-optical resonance in an atomic beam is limited by the longitudinal velocity of the atoms, the velocity of the order of 1 m/s and registration area length of at least 0.5 m are required for obtaining stability of 10^{-15}. The combination of these requirements, in turn, limits the allowable transverse velocity of the atoms in the beam.

The optical preparation of the atomic beam characterized by the longitudinal velocity of 1 m/s and a divergence of 0.05 rad is a difficult task due to the limitations of the existing slowing schemes. There are two types of these schemes – so-called “laser chirping”, and “Zeeman slowing”; the latter allows a continuous beam of cold atoms to be obtained, which is considered an advantage. In practice, however, none of these schemes in their classic versions provide a longitudinal deceleration of atoms below $10 \div 20$ m/s because of the significant time needed for slowing of atoms from the initial thermal distribution to a narrow velocity peak.

Therefore it was proposed[1] to significantly reduce the upper limit v_0 of the initial velocities of the atoms that interact with the laser radiation. In this case, the time of longitudinal deceleration dramatically decreases, which gives hope for obtaining the number of atoms with velocities ≤ 1 m/s sufficient for registration. The operating mode of such a slower is pulsed; some loss of intensity of the atomic beam occurs in this scenario, since only the slowest part of the thermal beam interacts with the cooling light. Thus, at a speed v_0 corresponding to one-half of the average thermal velocity, about 2% of a thermal beam are effectively used; this is compensated by shorter time (and hence the shorter slowdown length and less required power), and smaller transverse dimensions of the beam of atoms in the registration area..

In the present report, we numerically simulate the process of longitudinal cooling of the atomic beam in two slowing schemes, varying the initial velocity range and comparing the characteristics of the laser chirping and Zeeman slowing methods. We also examine the effectiveness of modifications of these methods implying use of a multimode cooling light. Estimates of the number of cold atoms required to obtain a stable CPT-Ramzey resonance signal are presented.

[117]V. S. Zholnerov, A. K. Vershovskiy, Yu. V. Rozhdestvenskiy, “Project of a Satellite Slow Beam Atomic Clock with CPT-Ramsey Registration”, Proc. EFTF-2012, Gothenburg, Sweden, p.320-322, 2012.