TWO-FREQUENCY SEPARATED OSCILLATING FIELDS TECHNIQUE FOR ATOMIC AND MOLECULAR BEAM INTERROGATION

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Abstract

We report on a novel method to reduce the effects of cavity phase shift upon atomic beam interrogation in Ramsey cavity configurations. Two distinct cavities driven at different frequencies are employed to produce a cavity phase shift which advances (or receeds) at a constant rate.

Nous indiquons une nouvelle méthode pour réduire les effets du déphasage en cavité sur l'interrogation par faisceau d'atomes dans diverses configurations de cavité de Ramsey. Deux cavités distinctes, excitées à différentes fréquences, sont employées pour produire dans la cavité un déphasage qui avance (ou retarde) à vitesse constante.

Introduction

The Ramsey technique[1] of separated oscillating fields for atomic beam spectroscopy is widely used in atomic frequency standards, specifically in the cesium beam standard which forms the present basis for the definition of frequency and time interval. The technique offers the advantages of narrow linewidth, relative freedom from first order Doppler effects, relaxation of certain constraints on field homogeneity in the drift region and relative ease of implementation.

A difference δ in the phase of the interrogating RF signals experienced by the atomic beam in the two Ramsey interaction regions leads to a displacement of the apparent line center by $\sim\frac{\delta}{\langle T\rangle}$ where $\langle T\rangle$ represents the average flight line between the interaction regions. Care in fabrication and assembly may reduce but cannot ultimately eliminate this source of error. Beam reversal, a procedure which is only practical for laboratory devices, yields information on the value of δ, but the accuracy of this procedure is limited by a similar effect, that of "distributed" phase error, which occurs as a result of a phase change across the transverse dimension of the interaction region. This latter effect, although generally smaller than the former effect, is much less tractable in analytical treatment.[2] These two effects are presently the most serious source of uncertainty in the evaluation of primary frequency standards.

We are attacking the phase shift problem by relaxing the constraint $\delta = 0$ and allowing the relative phase of the two interaction regions to advance (or receed) at a constant rate.[3] This will be implemented by driving two distinct cavities at two different frequencies near the cesium resonance. Details of such a technique are discussed below.

Discussion

The form of the spectral lineshape obtained by the method of separated oscillating fields in the presence of relative phase differences was developed by Ramsey.[1] The envelope bounding the lineshapes obtainable with various dc values of phase difference is straightforwardly obtained:[3]

$$S(\omega) = \{[\int dT\, B'(T)\cos(\omega-\omega_0)T]^2 + [\int dT\, B'(T)\sin(\omega-\omega_0)T]^2\}^{\frac{1}{2}} \qquad (1)$$

The envelope obtained under conditions where the relative phase in the two interaction regions varies at any reasonable rate (as we propose) may be analysed in a fashion similar to that of Ramsey's original work. The observed transition probability varies sinusoidally at the difference frequency with an amplitude exhibiting rather specialized symmetry.

From frequencies in cavities 1 and 2:

$$\omega_1 = \omega_0 + \lambda_1 \qquad (2)$$

$$\omega_2 = \omega_0 + \lambda_2 \qquad (3)$$

where ω_0 represents the cesium resonance frequency, we construct:

$$\overline{\lambda} = \tfrac{1}{2}(\lambda_1 + \lambda_2) \qquad (4)$$

$$\Omega = \tfrac{1}{2}(\lambda_2 - \lambda_1) \qquad (5)$$

(The traditional Ramsey separated oscillating fields technique is describable, in this context, by $\overline{\lambda} = \Omega = 0$.) The envelope ε, generated by the advancing or receeding phase may be described by:

$$\varepsilon^2 = \varepsilon_s{}^2(\overline{\lambda},\Omega) + \varepsilon_a{}^2(\overline{\lambda},\Omega) \qquad (6)$$

where

$$\varepsilon_s{}^2(\overline{\lambda},\Omega) = \varepsilon_s{}^2(-\overline{\lambda},-\Omega) \qquad (7)$$

$$\varepsilon_a{}^2(\overline{\lambda},\Omega) = -\varepsilon_a{}^2(-\overline{\lambda},-\Omega) \qquad (8)$$

The antisymmetric term, ε_a, which is proportional to the distributed cavity phase, vanishes for beam configurations exhibiting identical velocity distribution shapes for all atomic trajectories producing signal. (It also vanishes of course for cavities with no distributed phase, as in superconducting cavities.) The bias of cavity-to-cavity phase shift has thus been removed and the bias of the distributed phase shift is removed for beam optics which are not velocity selective. Optical state selection and detection[4] may be an attractive approach to this problem.

The technique of envelope generation and detection incurs some sacrifice in linewidth. The ability to detect line center is degraded little, however, for the following reasons. The slope of the envelope is effectively doubled due to its particular shape (the amplitude changes in a noncompensatory fashion both from above and from below). The usable slope is, with this consideration, reduced only twofold from the standard Ramsey lineshape for Maxwellian velocity distributions.

Square wave modulation, which is particularly well suited to the symmetric envelope interrogation described above, yields an additional degree of sensitivity in determining line center.

Atoms undergoing transitions in both interaction regions contribute an ac signal of frequency 2Ω at the detector. This signal generates the envelope of interest. The broad pedestal (the Rabi signal) arising from single cavity transitions contributes only a dc signal at the detector. The ability of this new method to distinguish against the Rabi signal of the adjacent magnetic dependent transitions in cesium eliminates baseline tilt errors as well as permits operation at lower C-fields with a resulting decrease in sensitivity to magnetic perturbations. Depending upon details of experimental design, reductions of 4 to 10 seem reasonable.

Conclusions

The two frequency atomic beam interrogation concept has the potential to remove the largest inaccuracy of primary frequency standards. Smaller commercial standards can similarly be improved, both in accuracy and in stability. These improvements result from an increase in interrogation sophistication through electronic techniques with a relaxation of some mechanical complexities. We will describe an experimental approach to implement the two frequency interrogation technique as well as present some preliminary results.

References

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