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Frequency Stabilization of CO_2 Lasers through Saturated Absorption in SF_6

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Abstract

Carbon dioxide lasers have been built with a new design for higher stability. The frequency stability is found to be better than three parts in 10^{11} when the lasers are free-running and two orders of magnitude better when they are stabilized on saturated absorption resonances of SF_6. We discuss the present limitations of stability, reproducibility and accuracy in these experiments.

1. Introduction

Carbon dioxide lasers have previously been frequency stabilized using a number of techniques including the Lamb dip [1], saturated fluorescence [2] and saturated absorption in an external cell [3, 4].

In this paper we report preliminary experiments using this last technique with SF_6 as the absorber and a new design for the CO_2 lasers. The Allan variance has been plotted both for free-running and frequency locked lasers. An estimate of the reproducibility is also given. The factors limiting the present performances are analyzed.

2. Laser Design and Free-Running Stability

The lasers are built from massive, hollow invar ingots one meter long and 15 cm in diameter with an internal hole (5 cm in diameter). A coaxial water-cooled pyrex tube is used for the discharge. Since the cavity has no Brewster window, a fused silica ring insulates the ends of the invar structure from one another.

The beat note of the two lasers is detected through a liquid nitrogen cooled Hg-Cd-Te crystal (bandwidth $\geqslant 50$ MHz), then sent into a Hewlett-Packard frequency computing counter to provide the Allan variance $\sigma(2, \tau, \tau)$ as a function of τ for a single laser. The free-running stability is given on Figure 1 and exhibits a short term

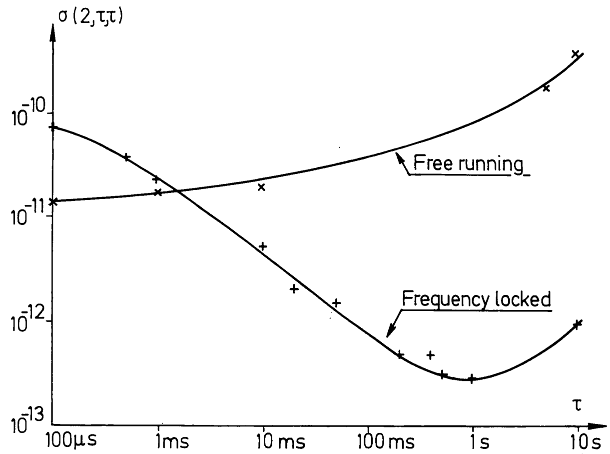

Fig. 1. Allan variance for free-running and frequency-locked CO_2 lasers

jitter less than 3 parts in 10^{11} ($\tau \leqslant 10$ ms). This limit can be improved by several methods:

- Use of sealed-off lasers.
- Reduction of acoustical disturbances with lead boxes.
- Improvement of the discharge current stability ($\Delta I/I = 5 \cdot 10^{-4}$ now), since current induced frequency changes are typically of the order of 1 MHz/mA.

3. Saturated Absorption Set-Up and Stability of the Frequency-Locked Lasers

For the present experiments we have used the coincidence of an SF_6 doublet ($\Delta\nu = 3100$ kHz) as well as a triplet ($\Delta\nu_1 = 500$ kHz, $\Delta\nu_2 = 505$ kHz, see Fig. 2) with the P(16) emission profile of the CO_2 laser at 947.743 cm^{-1}.

Each frequency modulated laser illuminates a saturated absorption ring in which the probe and saturating beams are distinct [3]. This geometry provides a good optical isolation of the lasers by the use of linear orthogonally polarized beams.

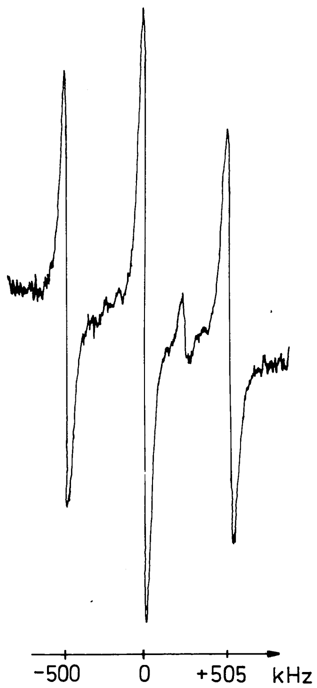

Fig. 2. Derivative Spectrum of the SF_6 triplet lying close to the center of the P(16) CO_2 line. (SF_6 pressure 0.13 Pa = 1 μmHg)

The 6 m long absorbing cells are filled with SF_6 under a few millitorrs pressure. The probe beam, detected with a cooled Hg-Cd-Te crystal is preamplified (bandwidth = 400 kHz at 3dB), then sent into the servo-loop which uses the first harmonic of the modulation signal. Modulation and length corrections are applied to a single PZT crystal. Under these conditions the peak-to-peak linewidth was 40 kHz.

Figure 1 also gives the Allan variance for each laser stabilized on each component of the doublet. The minimum, 8 Hz or 3 parts in 10^{13}, occurs for sampling times around one second. Stabilizing the lasers on the outer triplet resonances gave a reproducibility of 1 kHz (3 parts in 10^{11}) which was estimated by interchanging the transitions on which each laser was stabilized.

Factors limiting long-term stability, reproducibility and accuracy can be summarized:

–*Effects of the beam geometry*:
a) frequency shifts induced by curvature of the laser wavefront [5] (reduced in the ring geometry) and by fringe effects due to spurious reflections on beam splitters, windows and detectors.
b) open-air optical path fluctuations.

–Slow *pressure drifts* in the absorbing cells tilting the linear absorption baseline under the saturated absorption resonances. As one knows, this effect can be reduced by third harmonic modulation detection, or even better by phase-modulation of the saturating beam [3].

– *Differential saturation* of unresolved hyperfine (or Zeeman) components.

– *Instrumental shifts.*
a) modulation shifts and phase-sensitive-detection errors.
b) absence of filter for even modulation harmonics.
c) operational amplifiers temperature dependent offsets.

– *Second-order Doppler shift changes* owing to transverse velocity selection effects [5].

The recoil splitting (24 Hz) and direct pressure shifts will also have to be considered in further experiments.

4. Conclusion

With some improvements the CO_2 lasers stabilized on SF_6 (or OsO_4) lines can be comparable with He-Ne lasers stabilized on the CH_4 line (6). In fact, the high molecular weight of SF_6 (or OsO_4) offers some advantages with respect to geometrical shifts, second-order Doppler shifts and recoil structure. Higher resolution is still required to estimate the possible influence of the hyperfine structure in SF_6. A new set-up with 30 cm diameter beam optics has been built and is expected to give that answer.

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